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TECHNICAL MEMORANDUM NO. 3-240

TRAFFICABILITY OF SOILS

Eighteenth Supplement

DEVELOPMENT OF REVISED MOBILITY INDEX FORMULA FOR SELF-PROPELLED WHEELED VEHICLES IN FINE-GRAINED SOILS

by

J. G. Kennedy

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March 1968

Sponsored by

U. S. Army Materiel Command

Conducted by

U. S. Army Engineer Waterways Experiment Station

CORPS OF ENGINEERS

Vicksburg, Mississippi

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U. S. Army Materiel Command
Project No. 1-V-0-21701-A-046
Task 02

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Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

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FOREWORD

The tests reported herein were conducted in furtherance of Department of the Army Research and Development Project 1-V-0-21701-A-046, "Trafficability and Mobility Research," Task 1-V-0-21701-A-046-02, "Surface Mobility." This project is conducted under the sponsorship and guidance of the Directorate of Research and Development, U. S. Army Materiel Command.

Tests were conducted in the vicinity of Vicksburg, Mississippi, during January and February 1963, and at Ft. Eustis, Ft. Lee, and Camp Pendleton, Virginia, during February and March 1963.

Acknowledgement is made to the U. S. Army Transportation Board, Ft. Eustis, Virginia, for its cooperation and procurement of test vehicles used during the Virginia test program.

The study was conducted by personnel of the Soil-Vehicle Studies (SVS) Section, Vehicle Studies Branch (VSB), Mobility and Environmental (M&E) Division, U. S. Army Engineer Waterways Experiment Station (WES), under the general supervision of Mr. W. J. Turnbull, Technical Assistant for Soils and Environmental Engineering; Mr. W. G. Shockley, Chief of the M&E Division; Mr. S. J. Knight, Assistant Chief of the M&E Division; and Mr. E. S. Rush, Chief of the SVS Section, VSB. Mr. B. G. Stinson, Obstacle-Vehicle Studies Section, VSB, directed the field tests and performed preliminary analysis in the development of the revised mobility index formula reported herein. Mr. J. G. Kennedy, SVS Section, performed the statistical analysis of the original and revised mobility equations also reported herein. The report was prepared by Messrs. Kennedy and Rush.

Directors of the WES during the test program and preparation of this report were COL Alex G. Sutton, Jr., CE, and COL John R. Oswalt, Jr., CE. Technical Director was Mr. J. B. Tiffany.

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
yards	0.9144	meters
miles	1.609344	kilometers
square inches	6.4516	square centimeters
pounds	0.45359237	kilograms
pounds	4.448	newtons (N)
short tons (2000 lb)	907.185	kilograms
pounds per square inch	0.070307	kilograms per square centimeter
pounds per square inch	0.689476	N per square centimeter
pounds per cubic foot	16.0185	kilograms per cubic meter

Note: Conversion from British to metric units of measure should be made with caution in this report in connection with index values (cone index, rating cone index, vehicle cone index) and empirically derived mobility index formulas that are not dimensionally correct.

CONTENTS

SUMMARY

Studies of the trafficability of soils have been conducted by the U. S. Army Engineer Waterways Experiment Station (WES) since 1945. Results of these studies have been reported in WES Technical Memorandum 3-240, Trafficability of Soils series and in numerous Miscellaneous Papers. In 1955, the methods and techniques of measuring the trafficability of fine-grained soils were considered substantially complete and satisfactory, and a summary report (TM 3-240, Fourteenth Supplement) was published. That report contained formulas for computing mobility indexes (MI) and converting MI's to vehicle cone indexes (VCI), which is the minimum soil strength required for 50-pass go-no go performance, for all military wheeled and tracked vehicles in existence at that time. Since 1955 there has been a trend in wheeled-vehicle design toward larger high-flotation tires on small vehicles and much heavier wheel loads on much larger vehicles than the conventional 2-1/2- and 5-ton 6x6 trucks. Data from trafficability test programs conducted by WES and other agencies with vehicles mounted with construction-equipment-type tires indicated that the computed VCI was not in close enough agreement with test results. Therefore, to obtain supporting data to determine whether modification of the existing mobility index formula for self-propelled wheeled vehicles was necessary, field tests were conducted with vehicles similar to those mentioned above, and also with a few vehicles of more conventional design. Tests were conducted with five wheeled vehicles near Vicksburg, Miss., during January and February 1963, and with four wheeled vehicles at Ft. Eustis, Ft. Lee, and Camp Pendleton, Va., during February-March 1963 (data obtained from tests with one vehicle, the 5-ton forklift, were not used in this analysis).

The main purposes of this study were to (a) obtain adequate test data to determine experimentally the VCI for 50 passes for some untested vehicles and (b) use the results of these tests and others in which experimental VCI's were determined to develop a mobility index formula suitable for a wide range of vehicle weights and tire sizes.

The experimental VCI's determined for eight wheeled vehicles from the above-mentioned test programs and VCI's obtained from other test programs for eight additional wheeled vehicles are included herein. Although only 16 vehicles were used in the test programs, VCI's were determined for 20 vehicle "types" including tests with four of the vehicles modified as follows (each modification was considered as a separate vehicle): 16-ton XM438E2 GOER tested with and without chains, 3/4-ton M37 tested at two wheel loads, 2-ton Meili Flex-Trac tested as a 4x4 and

as a 6x6, and the 5-ton XM520 GOER tested with two tire sizes. To determine if improvement in predicting VCI could be made, a statistical analysis was performed on both the original and revised MI formulas. This analysis involved the use of a multiple linear regression technique wherein mobility index formulas were produced that considered the best interrelation of the eight vehicle factors in the formulas. Evaluation of the results of the statistical analysis was made in terms of VCI unit error, VCI percent error, multiple correlation coefficient (R^2), and standard error of regression equation. Comparison of the average experimental VCI's and average VCI's computed by the four mobility index formulas are shown below.

	Vehicle Cone Index			
	Unit Error		Percent Error	
Formula	Absolute Average	Range	Absolute Average	Range
Original	19.0	1-132	26.4	2.0-130.0
Original (regression)	9.1	0-34	18.7	0-91.9
Revised	3.6	0-9	6.1	0-14.5
Revised (regression)	3.2	0-7	6.1	0-20.0

The general conclusions are that considerable improvement can be made in the original formula merely by using the multiple regression equation, since this technique permits the computation of a dependent variable (MI) when two or more independent variables (vehicle factors) are related to the dependent variable. The accuracy of the computed variable depends upon the degree of relations between the dependent and independent variables. Further improvements in computing VCI can be made using the revised formula. By using the more complicated multiple regression form of the revised formula factors, still further improvements in computing VCI can be made. However, since the increased accuracy of the revised multiple regression formula over the revised formula is only slight (see tabulation above), it is suggested that the revised formula be adopted, especially for field application.

Also included in this report is a check on the validity of the revised MI formula in which individual test results from test programs with vehicles different from those used in revising the MI formula are compared with the computed VCI of each vehicle.

Appendix A presents the original and revised mobility index formulas and comparisons of computed VCI's for some standard and experimental military vehicles using the two MI formulas. Appendix B presents a detailed analysis and evaluation of the original and revised MI formula factors by the multiple linear regression technique.

TRAFFICABILITY OF SOILS

DEVELOPMENT OF REVISED MOBILITY INDEX FORMULA FOR SELF-PROPELLED WHEELED VEHICLES IN FINE-GRAINED SOILS

PART I: INTRODUCTION

Background

1. Studies of the trafficability of soils have been in progress since 1945 at the U. S. Army Engineer Waterways Experiment Station (WES) and have been reported primarily in WES Technical Memorandum No. 3-240, Trafficability of Soils, and 17 supplements thereto, but also reported in numerous WES Miscellaneous Papers. Basically, this research is aimed at the development of instruments and techniques for the measurement of surface media and the prediction of performance of military vehicles on these media. Thus far studies have been made on four general types of surface media: fine-grained soils, coarse-grained soils (sand beaches and deserts), organic terrain (muskeg), and snow. The early phases of the work were studies primarily of fine-grained soils. In 1955, the methods and techniques of measuring the trafficability of fine-grained soils were considered essentially complete, and a summary report (TM 3-240, Fourteenth Supplement) was published. This report contained formulas for computing the mobility indexes and predicting the minimum soil strength requirements for 50-pass "go-no go" performance of all military vehicles in existence at that time. Since 1955, there has been a trend in wheeled-vehicle design toward larger high-flotation tires on small vehicles and much heavier wheel loads on much larger vehicles. Examples of large tires are those on members of the GOER family of vehicles, and the low-profile Terra-tires used as replacements for more conventional tires on standard military vehicles. Examples of heavy wheel loads are the 25- and 50-ton* wheel loads of the BARC (Barge, Amphibious, Resupply, Cargo), a 60-ton

* A table of factors for converting British units of measurement to metric units is presented on page ix.

special-purpose barge, and the approximate 10-ton wheel loads of the 16-ton GOERS.[1,2]

2. Data from limited test programs conducted with vehicles mounted with construction-equipment-type tires--a Tournadozer,* a 5-ton GOER,[3] a 5-ton Jumbo truck,[4] two large LeTourneau industrial vehicles[5]--and from results obtained from test programs such as Project Wheeltrack[1] and Swamp Fox II[2] conducted by other agencies indicated that the computed vehicle cone index (VCI) values were not in close enough agreement with test results to permit the prediction of vehicle performance with the desired degree of accuracy. Supporting data to determine whether modification of the existing formula for self-propelled wheeled vehicles was necessary were obtained from field tests conducted with vehicles similar to some of those tested in the above-referenced studies, and also with a few vehicles of more conventional design.

Purpose and Scope

3. The main purposes of this study were to (a) obtain adequate test data to determine experimentally the vehicle cone index (VCI) for 50 passes for vehicles mounted with nonconventional tires and (b) use results of the field tests to develop a revised mobility index (MI) formula for self-propelled wheeled vehicles.

4. The adequacy of the revised MI formula was checked by comparing the experimentally determined VCI's with VCI's computed by both the original and the revised MI formulas. In addition, results of other test programs were used to check the revised formula. These are discussed as appropriate in the analysis. The two MI formulas are presented in Appendix A. Tables also are presented in Appendix A listing a range of standard military wheeled vehicles and 19 wheeled vehicles of experimental designs that have been tested by the U. S. Army but as yet have not been accepted as military standard. The tables show VCI's computed with both the original and revised formulas. Detailed statistical analysis and evaluation

* Unpublished.

of both MI formulas are given in Appendix B.

5. The tests reported herein were conducted during two field programs: one near Vicksburg, Miss., and the other at three military installations in Virginia. Five wheeled vehicles (one vehicle was tested at two different loads) were used in the Vicksburg tests and four vehicles were used in the Virginia tests.

Definitions

6. Definitions of terms used in this report are given in TM 3-240, Fourteenth Supplement.

PART II: FIELD TEST PROGRAM

7. Tests were conducted near Vicksburg, Miss., during January-February 1963, and at Ft. Eustis, Ft. Lee, and Camp Pendleton, Va., during February-March 1963. Tests consisted of operating self-propelled wheeled vehicles across level, fine-grained soils and coarse-grained soils with fines, poorly drained. Observations of vehicle performance and measurements of pertinent soil and vehicle data were made for each test. Details of the various test areas, vehicles tested, test procedures, and data collected are discussed in the following paragraphs.

Test Areas

Vicksburg test area

8. This test area was on the southeast bank of Albemarle Lake, a small body of water on the Louisiana-Mississippi border approximately 16 miles north of Vicksburg (fig. 1). The water level of this lake rises and falls with that of the Mississippi River, which feeds it. At the time of testing (January and February 1963), the river was low, and a wide, flat expanse of lakeshore was exposed and accessible. The shoreline for a distance of about 400 ft from the lake was practically void of vegetation. Inland from this open area was an area that extended for about 300 yd on which willow trees with trunk diameters ranging from 6 to 10 in. were growing. Views of the areas are shown in fig. 2. Tests were conducted in both the

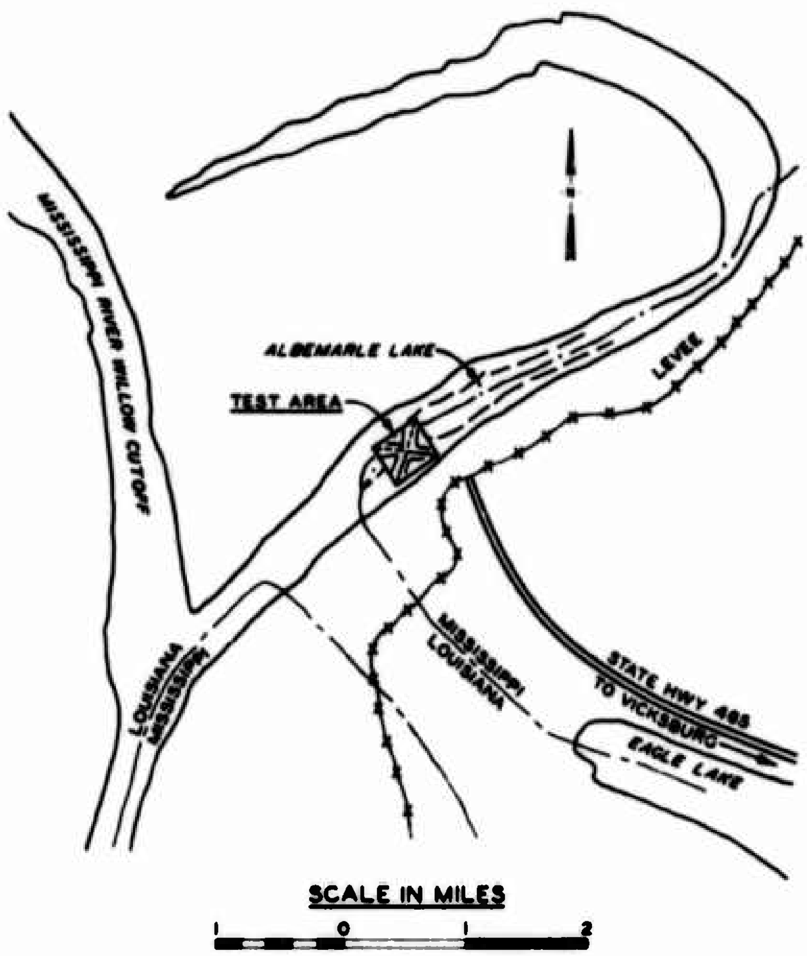


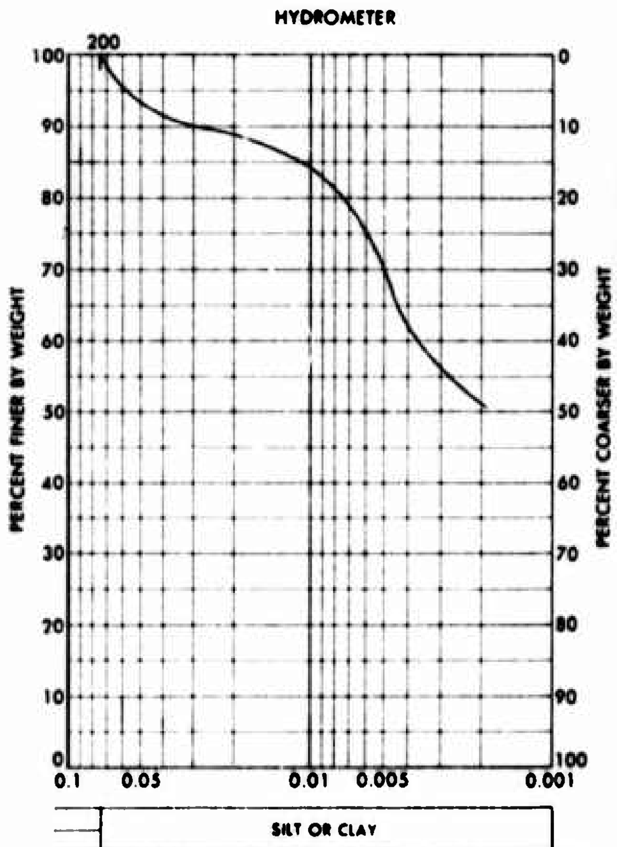
Fig. 1. Location of Vicksburg test area

open and wooded areas. The soil to a depth of 18 in. was classified as heavy (fat) clay, CH, according to the Unified Soil Classification System (USCS) (fig. 3). A gradual decrease in moisture content with increase in distance from the water's edge permitted testing on a range of soil strength conditions that was wide enough to represent "go" and "no go" conditions

a. Open area

b. Wooded area

Fig. 2. Vicksburg test area



ELEV OR DEPTH	CLASSIFICATION	LL	PL	PI
0- TO 18-IN.	FAT CLAY (CH)	87-92	32-34	55-58

Fig. 3. Gradation curve and classification data, Vicksburg test area soil

for all vehicles tested.

Virginia test areas

9. Ft. Eustis. This test area was located on the Ft. Eustis Military Reservation. The general location is shown in fig. 4, and a photograph of the area in which the tests were conducted is shown in fig. 5.

10. The test area was marshy and covered with tall grass. The 0- to 6-in. layer of soil contained a dense root mat. A gradation curve could not be determined

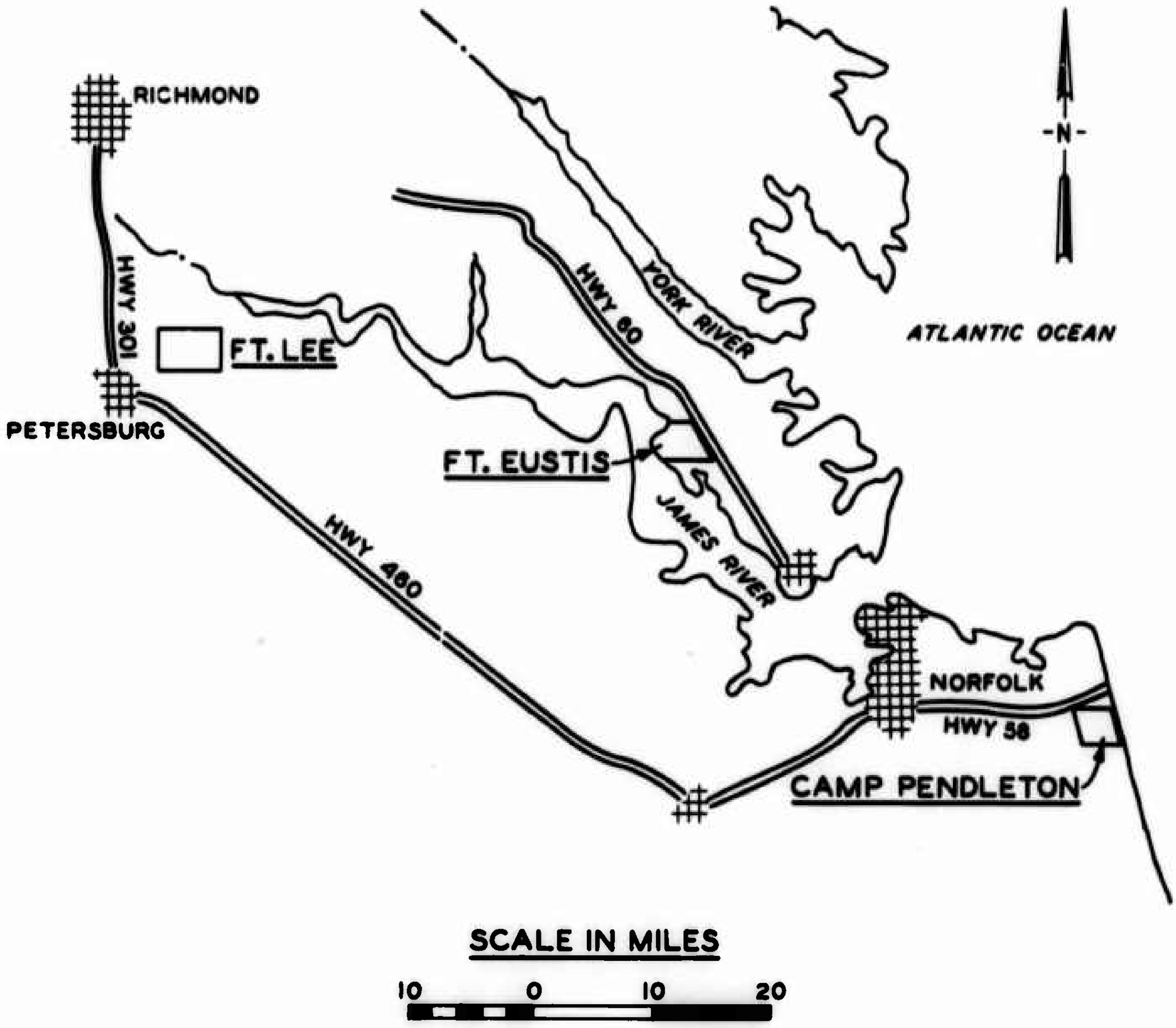
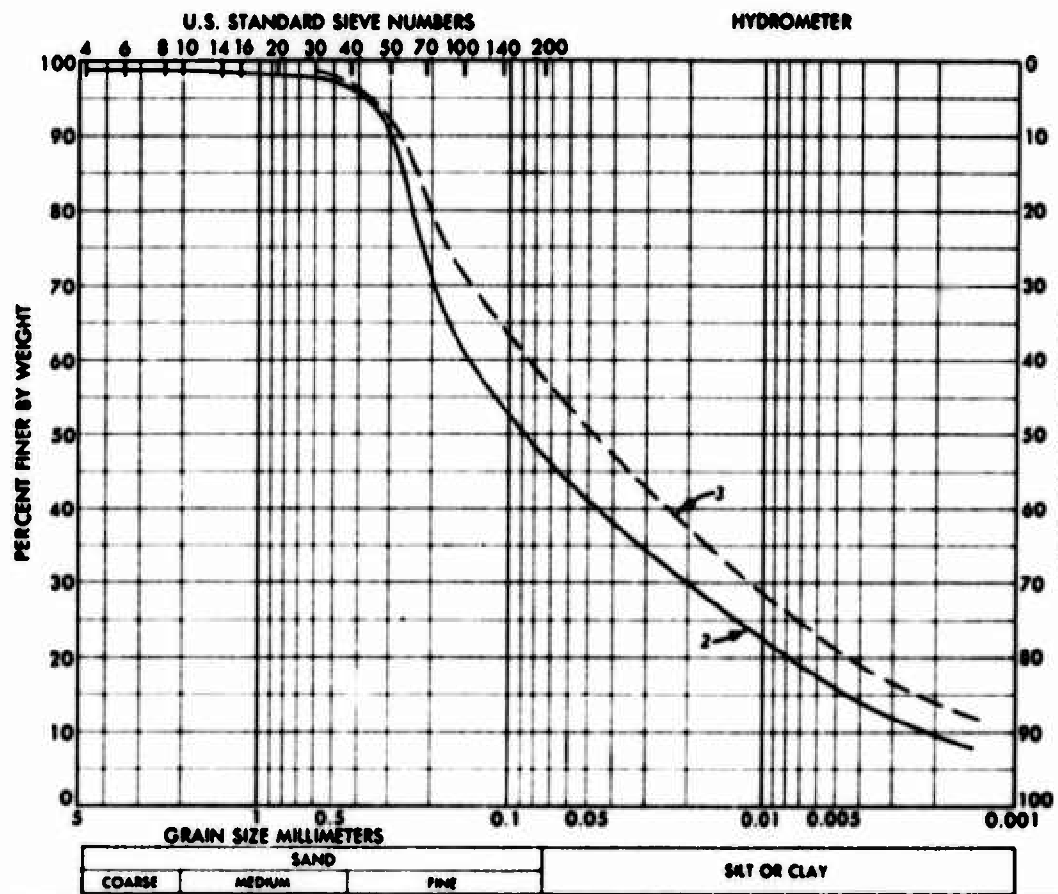


Fig. 4. Location of Virginia test areas

Fig. 5. Ft. Eustis test area

for the 0- to 8-in. (approximate) layer of soil because of too much organic material, but gradation curves for the soil below 8 in. along with classification data are shown in fig. 6. The soil type varied within the soil

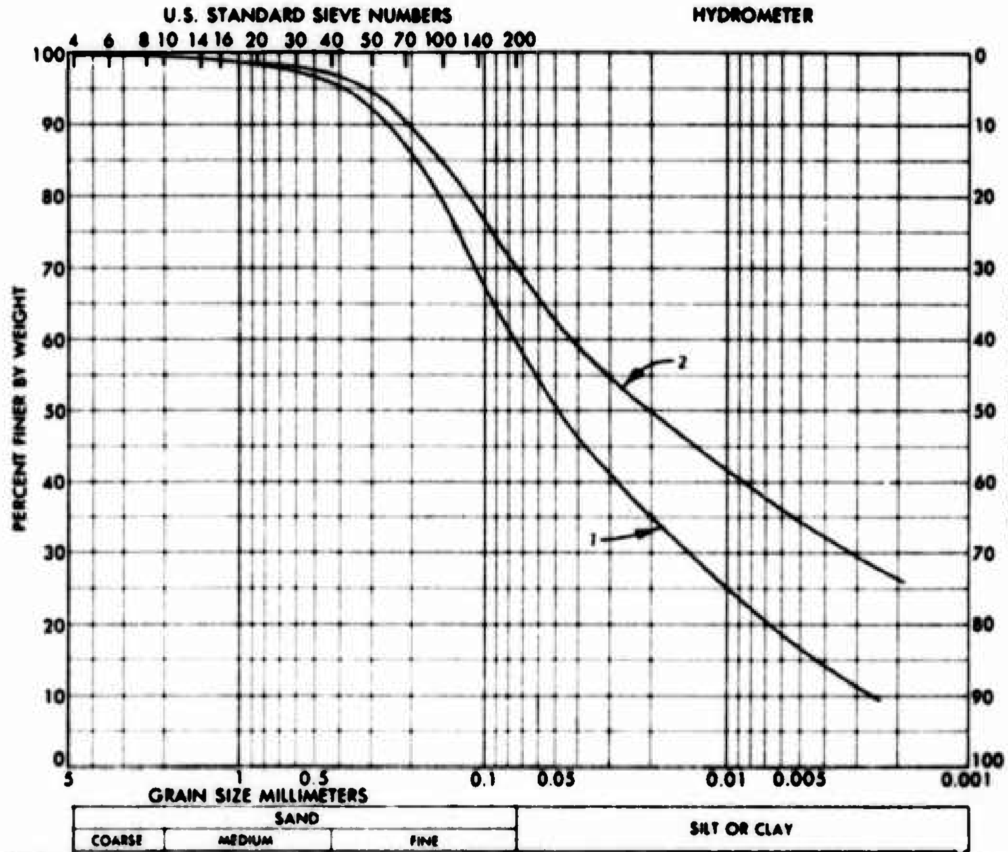


SAMPLE NO	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
--	0- TO 8-IN.	Pt		--	--	--
2	8- TO 12-IN.	SANDY CLAY (CH)		64	20	44
3	12- TO 18-IN.	FAT CLAY (CH)		65	19	46

Fig. 6. Gradation curves and classification data, Ft. Eustis, Va., test area soil

profile: that in the 0- to 8-in. layer was highly organic (Pt): that below 8 in. was a sandy clay (CH) to about 12 in. where a fat clay (CH) was encountered.

11. Ft. Lee. This test area was near the Ft. Lee Army Airport. Tests were conducted in a level to slightly sloping area of coastal plain deposits. The top soil layer was a very fine sandy silt (CL-ML), which varied in thickness from the surface to about 8 to 18 in., underlain by a lean clay (CL). Below the lean clay was a fairly stiff, mottled lean clay (CL) or fat clay (CH) (see fig. 7). The clay soil supported a perched water table that varied from the surface to 12 in. below the surface. Most



SAMPLE NO	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
1	0- TO 8- TO 18-IN.)	SANDY SILT (CL-ML)		24	18	6
2	8- TO 18-IN.	LEAN CLAY (CL)		28-35	14	14-21
--	BELOW 18 IN. (APPROX)	MOTTLED LEAN CLAY (CL)		(NO LIMITS DETERMINED)		

Fig. 7. Gradation curves and classification data, Ft. Lee, Va., test area soils

of the area had recently been logged, and tree stumps 8 to 15 in. in diameter and 10 to 20 in. high, spaced randomly at about 8- to 15-ft intervals, remained on the site. A dense grass covered the area, and there were scattered clumps of small trees with trunks up to about 4 in. in diameter growing on the site. Views of the area are shown in fig. 8. The general location is shown in fig. 4.

12. Backshore area south of Camp Pendleton. This test area was on the backshore area of the beach south of Camp Pendleton, Va. (see fig. 9). The tests were conducted in an area where a recent storm had washed away most of the clean sand, leaving a fine-grained soil exposed that ranged from a silty clay to a clayey silt. However, before the tests were conducted, a thin layer of sand about 1/2 to 1 in. thick had covered the fine-grained soil so that the area had the appearance of a normal

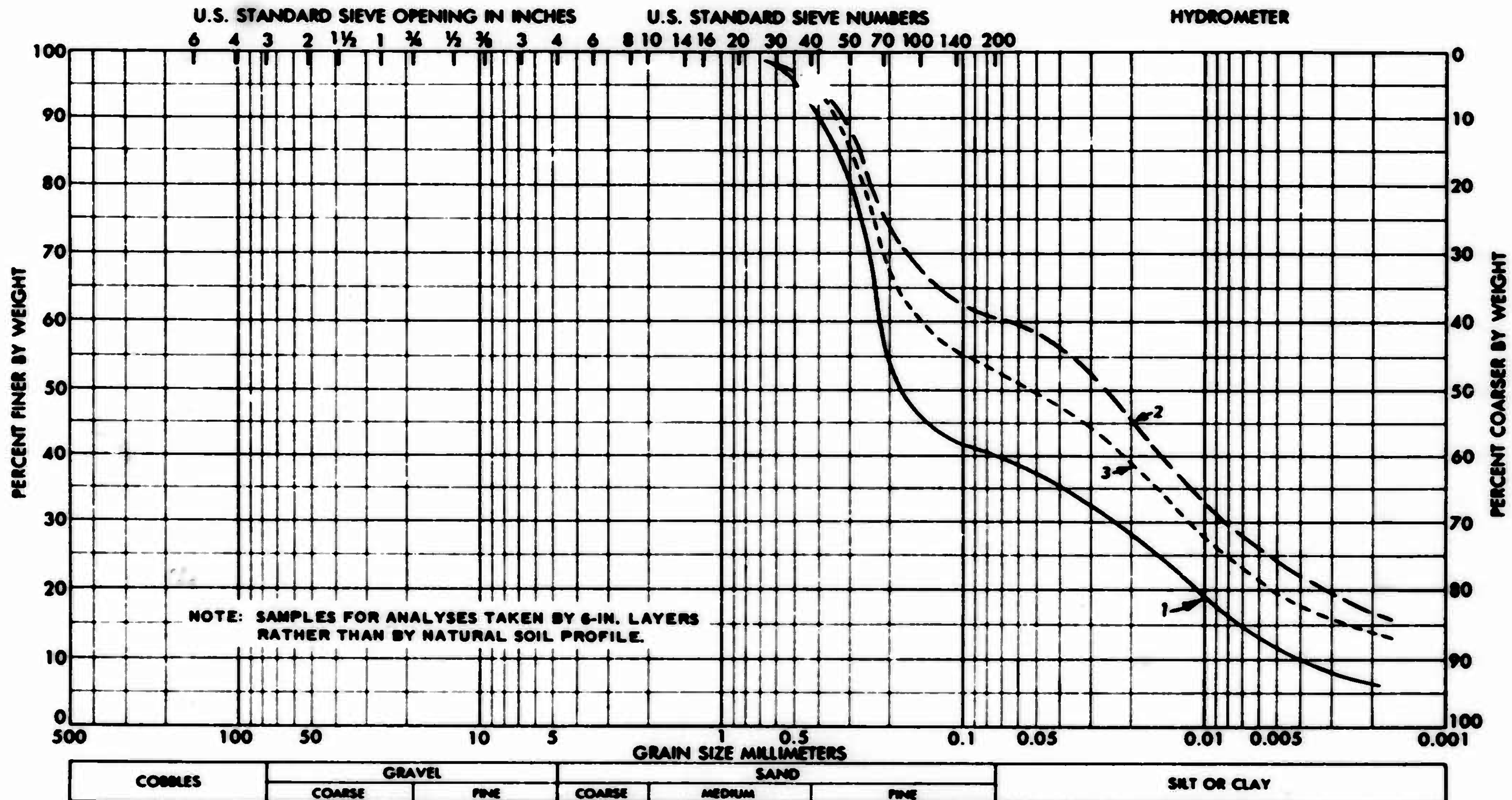
a. Looking south

b. Looking north

Fig. 8. Ft. Lee test area

Fig. 9. Beach area, south of Camp Pendleton

beach. The area was completely void of vegetation. Results of tests of soil samples taken at 6-in. increments for the 0- to 6-in. (excluding the surface sand layer), the 6- to 12-in., and the 12- to 18-in. layers of soil are shown and classification data are given in fig. 10.

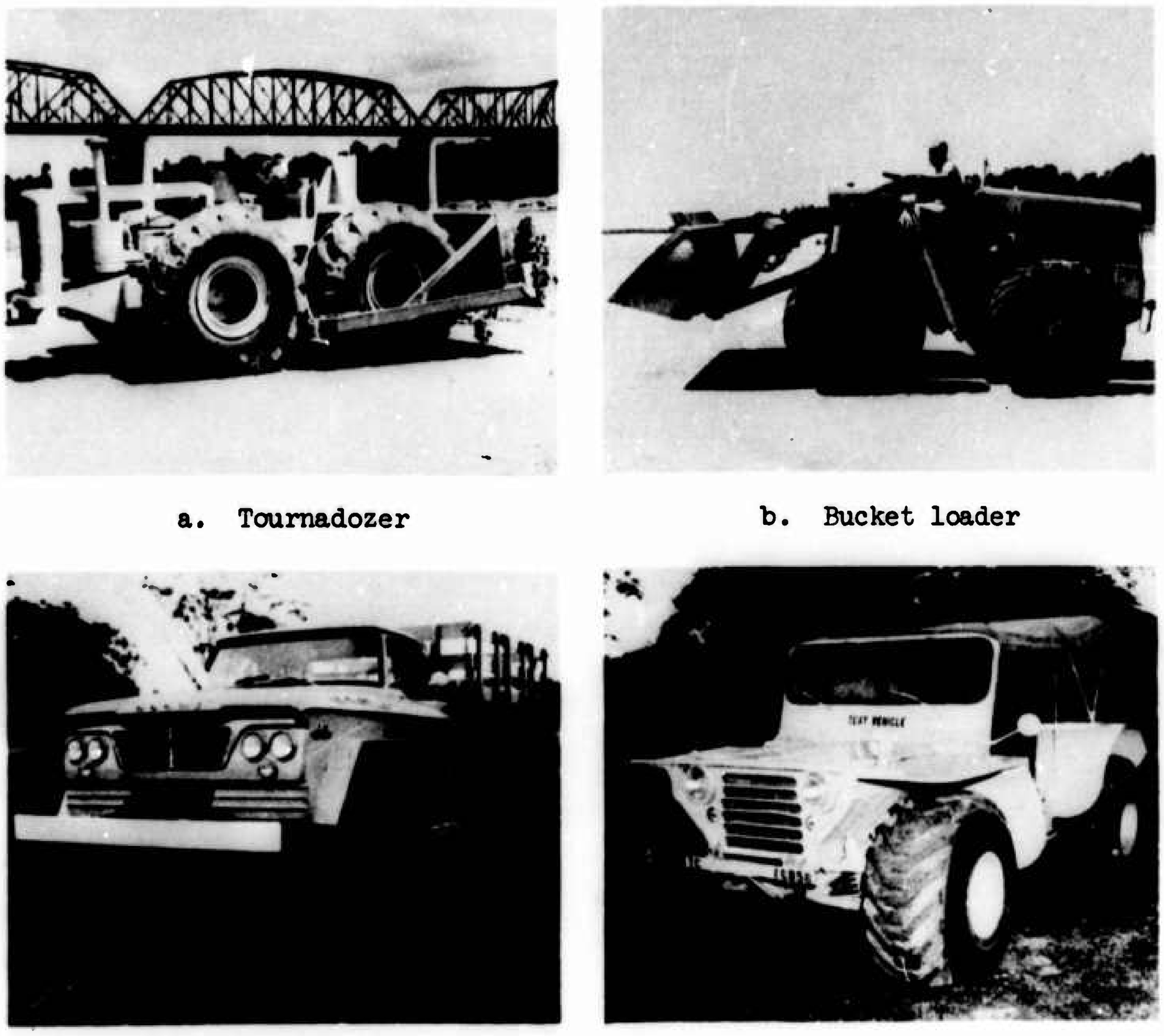


SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
1	0- TO 6-IN.	SILTY OR CLAYEY SAND (SM-SC)		21	14	7
2	6- TO 12-IN.	SANDY SILT (CL-ML)		19	13	6
3	12- TO 18-IN.	SANDY CLAY (CL)		24	13	11

Fig. 10. Gradation curves and classification data, Camp Pendleton, Va., test area soils

Vehicles Tested

13. Pertinent vehicle data and areas where each vehicle was tested are presented in table 1. Photographs of the vehicles are shown in fig. 11.



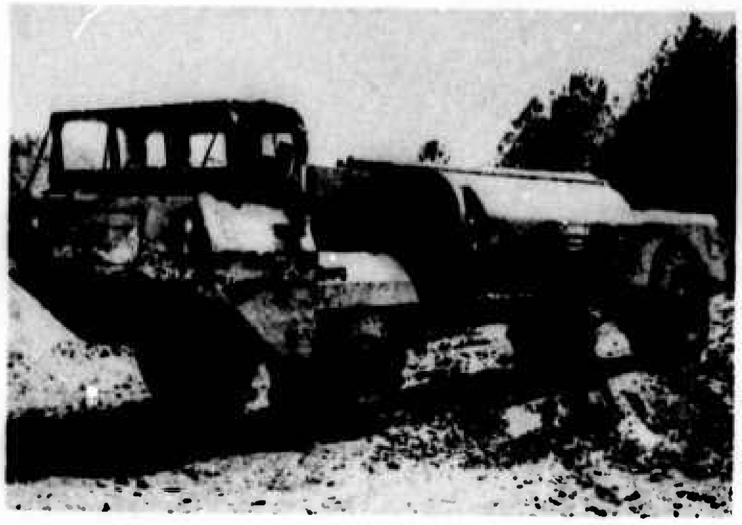
a. Tournadozer

b. Bucket loader

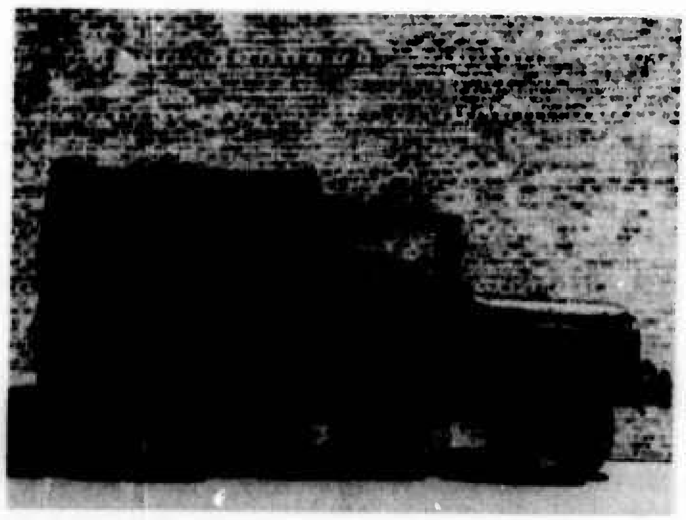
c. 1-1/2-ton W300 modified with low-pressure pneumatic tires

d. 1/4-ton M151 modified with low-pressure pneumatic tires

Fig. 11. Vehicles used in tests (1 of 2 sheets)



e. 16-ton XM438E2 GOER tanker



f. 3/4-ton M37 truck

g. 5-ton forklift

h. Willys station wagon

i. 1/2-ton M274 carrier (mule)

Fig. 11. (2 of 2 sheets)

14. Vehicles used in the Vicksburg tests were furnished by WES, and those used in the Virginia tests were furnished by the U. S. Army Transportation Board, Ft. Eustis, Va., except for the rough-terrain forklift, which was furnished by a support unit at Ft. Lee, Va.

15. All the vehicles used in the Vicksburg tests were equipped with standard tires, rims, and other vehicle components. Two of the four vehicles--the W300 and the M151--tested in Virginia were equipped with large high-flotation pneumatic tires that required the addition of power steering; but the other two--the GOER and the forklift--were equipped with standard tires and rims.

16. The vehicles tested were in good mechanical condition, but the M274 (mule) did not have sufficient power to turn its wheels in some test soils. Where lack of power appeared to affect results, this fact is mentioned in the "Remarks" column in the data tables. The tires on the Tournadozer were badly worn; this may have had some effect on its performance.

Vehicle Test Procedures

17. Test lanes were selected to minimize, insofar as possible, the effects of factors such as surface geometry, slope, vegetation, litter, and roots on vehicle performance. During the tests, observations were made and pertinent notes were recorded of the performance of the vehicle and the reaction of the soil. Insofar as possible, vehicle factors for a given vehicle were kept constant for each series of tests; tire pressures were checked and adjusted when necessary; the same gear ratios were used for all tests; and loads were not allowed to shift within the cargo beds, etc. Test lanes approximately 100 ft long were staked out, and soil data were collected along the expected paths of the left and right wheels of the vehicle. The vehicle then traveled over the test lane in a straight line at approximately 2 mph. After the vehicle had traveled through the test lane to a point where the rear wheels were about 5 to 10 ft beyond the end of the lane, the vehicle was put in reverse gear and driven back to the starting point in the same tracks to complete the second pass.

Traffic was continued until the vehicle was immobilized or until 50 passes were completed. Periodically during the tests, data were taken in the ruts.

Data Obtained

18. A summary of the data collected in the tests is given in table 2; these data are described in the following paragraphs.

Cone index

19. Cone index was measured with the cone penetrometer before and during traffic.

a. Before traffic. Cone index was measured at 10-ft horizontal intervals along the proposed path of each wheel at the surface and at 3-in. vertical increments to a depth of 24 in., and at 30- and 36-in. depths.

b. During and after traffic. Cone index was measured after various passes during the test and after the test was completed at the same horizontal and vertical intervals along the path as before traffic.

Remolding index

20. Remolding indexes were measured at three locations in the test lane before traffic was applied. The soil layers measured varied with the different vehicles (see table 2).

Rating cone index (RCI)

21. Rating cone index was computed from the average cone index and remolding index that were taken before traffic.

Moisture content and density

22. Samples for determination of moisture content and density were taken at the same locations as those where remolding indexes were measured and usually from the following soil layers: 0 to 6 in., 6 to 12 in., and 12 to 18 in.

Bulk soil samples

23. Representative bulk soil samples of the 0- to 6-in., 6- to 12-in., and 12- to 18-in. layers were obtained for soil classification purposes.

Rut depths

24. The depths of the ruts were measured usually on the same passes as those on which cone indexes were measured.

Photographs

25. Movies and still photographs were made of test areas and vehicles, as well as of pertinent features of the tests.

Data Analyses

26. The analyses of data consisted mainly of the determination of the minimum soil strength in terms of rating cone index (RCI) required to support each vehicle for 50 passes. RCI was the main soil measurement considered; however, the occurrence of undercarriage dragging, and the degree of difficulty experienced by the vehicle in traversing the test lane were considered in the analyses.

Review of RCI, VCI, and critical layer

27. Previous trafficability studies have shown that the ability of a soil to sustain repetitive traffic (50 passes) of wheeled and tracked self-propelled vehicles can be predicted from measurements of RCI. The RCI that is just adequate to support 50-pass traffic of a particular vehicle is designated as the vehicle cone index (VCI). Test results have shown that there is a critical layer, i.e. a layer whose strength (RCI) appears to be most closely related to vehicle performance. For most vehicles this layer has been determined to be approximately 6 in. thick. The depth of the critical layer is dependent upon the weight of the vehicle and the characteristics of the soil strength profile. If the critical layer and the 6-in. layer below the critical layer have the same strength or show an increase in strength with depth, the strength profile is considered normal. If the 6-in. layer below the critical layer has less strength than the normal critical layer, the strength profile is considered abnormal and the deeper layer is considered the critical one for evaluation purposes.

Determination of experimental VCI for 50 passes

28. Summaries of data collected before, during, and after traffic, together with a description of the performance of the vehicles and other pertinent remarks are given in table 2. The data are shown graphically in plate 1 where soil strength in terms of RCI is plotted along the horizontal scale; the vertical scale has no quantitative values.

29. Although earlier studies concluded that depth to critical layer varied with vehicle weight and soil strength profile, data were examined by 6-in. layers from the surface through the 12- to 18-in. layer to determine (in the case of vehicles with high-flotation tires) and to verify (in the case of more conventional vehicles) critical layers previously established. Results of this preliminary examination to determine critical layer are as follows:

Vehicle	Critical Layer in.	Vehicle	Critical Layer in.
XM438E2	6-12	M37 empty	6-12
Tournadozer	6-12	M37 loaded	6-12
Bucket loader	6-12	Willys station wagon	6-12
1-1/2-ton power wagon	6-12	M151 modified	3-9
		M274	3-9

RCI values underlined in table 2 are plotted in plate 1 for determination of VCI. It should be remembered that if the RCI of the 6-in. layer below the normal critical layer is less than the RCI of the normal layer, then the lower RCI value was used in the analysis and the minimum RCI that would permit a given vehicle to complete 50 passes is the experimental VCI of that vehicle.

30. Tests with 16-ton XM438E2. Fourteen tests were conducted with the XM438E2 at Ft. Lee. The vehicle was equipped with chains for eight tests and was tested without chains in six tests. Since a load was not available, all tests were conducted with the vehicle empty, which resulted in unequal weight distribution on the two axles; the front axle carried 24,300 lb and the rear axle carried 14,010 lb. The unequal weight may have hampered vehicle performance, but this could not be determined from

observation of the tests. In most tests when the vehicle became immobilized, it was able to extricate itself by using its "wagon steer" feature, which allowed the front end to turn at right angles to the direction of travel.

a. XM438E2 with chains. A graphical presentation of data from these tests is given in plate 1a. From examination of the plot, it can be seen that in test 29 the vehicle completed 50 passes with some difficulty on an RCI of 48, but in tests 31 and 32 it became immobilized during the 4th and 6th passes on RCI's of 56 and 57. Test notes indicate that in tests 31 and 32 the vehicle undercarriage was not dragging and the vehicle could go by applying its unique wagon steering action, which indicates that early pass immobilizations were caused in part by low traction capacity of the soil. In test 30 on an RCI of 81, the vehicle had difficulty on the first and second passes because of a soft spot in the test lane which caused some traction failure, but after the soil from the soft spot had been moved out of the ruts by the wheels, traffic was continued until 50 passes were completed with no further difficulty. From these tests it was determined that the 6- to 12-in. layer was the critical layer for the unloaded vehicle; however, when the vehicle is loaded with a 16-ton pay load, the critical layer may well be deeper. A wide range of RCI was not tested, and an experimental VCI could be tentatively determined only after examination of results of tests with chains and performance of the Tournadozer with similar average wheel loads. The experimental VCI was determined tentatively to be 60.

b. XM438E2 without chains. RCI-vehicle performance relations for these tests are shown in plate 1b. No immobilizations were obtained after the fourth pass in any test; however, considerable wheel slip was experienced in test 21 and 14- to 15-in. ruts developed in tests 21 and 22 on RCI's of 89 and 76. The experimental VCI of the XM438E2 without chains was determined to be 62, or two units higher than with chains. Previous testing[6] indicated that chains would improve performance in soft soils by about that amount. A typical test is shown in fig. 12.

31. Tests with the Tournadozer. RCI-vehicle performance relations are shown in plate 1c. Nine tests were conducted; six resulted in immobilizations and three resulted in completion of 50 passes, although in test 8 the vehicle experienced considerable difficulty on an RCI of 59. In test 4 on an RCI of 62 the vehicle completed 50 passes with no

a. After 5 passes

b. After 21 passes

c. After 50 passes

Fig. 12. Test 21, 16-ton XM438E2 GOER (tanker), Ft. Lee test area

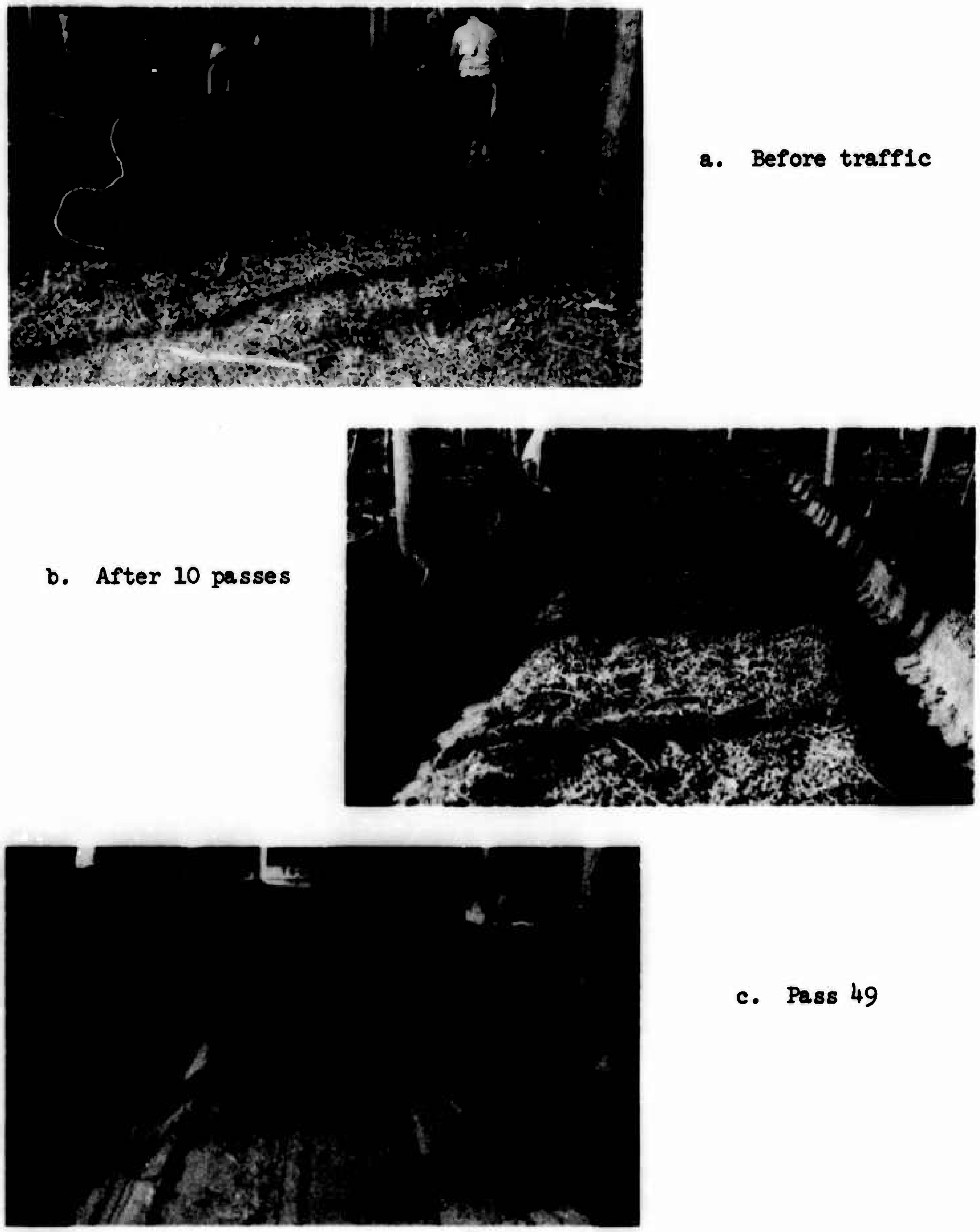
difficulty although its undercarriage was dragging after about 36 passes. Photographs of test 4 are shown in fig. 13. The experimental VCI for the Tournadozer was determined to be 60 for safe completion of 50 passes.

32. Tests with the 5-ton forklift. Attempts were made to determine the experimental VCI for this vehicle at Ft. Lee, but at the time of testing the soil was too soft to permit more than a few passes before immobilization occurred; therefore, an analysis was not performed but the data are presented in table 2 as a matter of record.

33. Tests with the bucket loader. RCI-vehicle performance relations are shown in plate 1d. Thirteen tests were conducted; eight resulted in immobilizations before 50 passes were completed and five resulted in completion of 50 passes. However, of the five tests successfully completed, the results of tests 24 and 32 were in doubt since test notes state that in test 24 on an RCI of 44 the undercarriage began dragging on about the 33d pass, and in test 32 on an RCI of 40 the undercarriage began dragging on about the 17th pass and extremely high slip occurred on the last few passes. Test notes also state that in test 23 a mat of tree roots may have enabled the vehicle to complete 50 passes on an RCI of 52. The experimental VCI was determined to be 50 for the bucket loader. Photographs of tests 32, 45, and 46 are shown in fig. 14.

34. Tests with the 1-1/2-ton power wagon. RCI-vehicle performance relations are shown in plate 1e. Eleven tests were conducted with this vehicle, one at Ft. Eustis, seven at Ft. Lee, and three at Camp Pendleton. Photographs of test 57 at Camp Pendleton are shown in fig. 15. A good separation between immobilizations and nonimmobilizations is shown in plate 1e. The vehicle was equipped with low pressure pneumatic tires, which appeared to help considerably when traveling over soft soil. It was noted that most immobilizations occurred without undercarriage dragging but with only one wheel on each axle spinning. The use of a device to lock out differential action might have enabled the vehicle to complete the test in a number of instances where it became immobilized. The experimental VCI was determined to be 42.

35. Tests with the 3/4-ton M37 truck. Sixteen tests were conducted with this vehicle: ten with the vehicle empty and six with a 3/4-ton



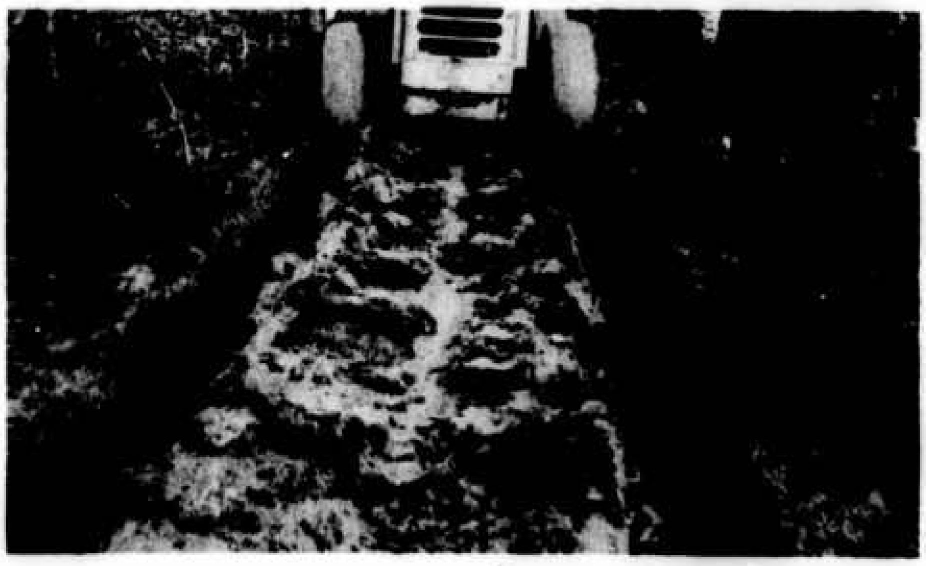
a. Before traffic

b. After 10 passes

c. Pass 49

Fig. 13. Test 4, Tournadozer in wooded area, Vicksburg test program

a. Test 45 immobilized on first pass attempting to enter test lane



b. Test 46 immobilized on 5th pass

c. Test 32 immobilized on 11th pass

Fig. 14. Bucket loader tests at Vicksburg

a. Ruts after 1 pass

b. Immobilized on 4th pass

c. Immobilized on 4th pass. Note mud boil in center of ruts

Fig. 15. Test 57, 1-1/2-ton power wagon on backshore beach area south of Camp Pendleton

pay load. All tests were conducted at Vicksburg, Miss.

a. Tests with empty M37. RCI-vehicle performance relations are shown in plate 1f. Four tests resulted in immobilizations before completion of 50 passes, and six tests resulted in the vehicle successfully completing 50 passes. Test notes indicate that all nonimmobilization tests were begun with the vehicle operating with only two wheels driving. Test notes also indicate that in four of these tests the vehicle experienced serious difficulty. It is not known to what degree operation with only two driving wheels in early passes contributed to the difficulty after all wheels were driving. It is assumed that the portion of the tests conducted with two wheels driving had an adverse effect, and a few of the tests where difficulty was experienced would have been completed with less difficulty if all wheels had been driving for all passes. Therefore, it was determined that the experimental VCI for the empty M37 was 50; this value is considered to be slightly conservative.

b. Tests with loaded M37. RCI-vehicle performance relations are shown in plate 1g. Six tests were conducted; five ended in immobilizations before completion of 50 passes and one (test 68) ended with the vehicle completing 50 passes. In test 68 on an RCI of 55 the vehicle had difficulty completing the test because of dragging of undercarriage. From the results of test 68 and the experimental VCI of the empty M37, the experimental VCI of the loaded M37 was estimated to be 58.

36. Tests with the Willys station wagon. Seven tests, all at Vicksburg, were conducted with this vehicle; six resulted in immobilizations and one resulted in successful completion of 50 passes. RCI-vehicle performance relations are shown in plate 1h. The best separation of the go tests from the no go tests was for the 6- to 12-in. layer; therefore, this was considered to be the critical layer. Test 90, on an RCI of 42, resulted in a 14th-pass immobilization when the sticky clay soil accumulated beneath the fenders and jammed the wheels. In tests 88 and 89 on 47 and 46 RCI's, respectively, the vehicle completed 31 and 47 passes before immobilizing. In test 91, 50 passes were completed relatively easily even though the undercarriage of the vehicle was dragging. Experimental VCI was determined to be 50.

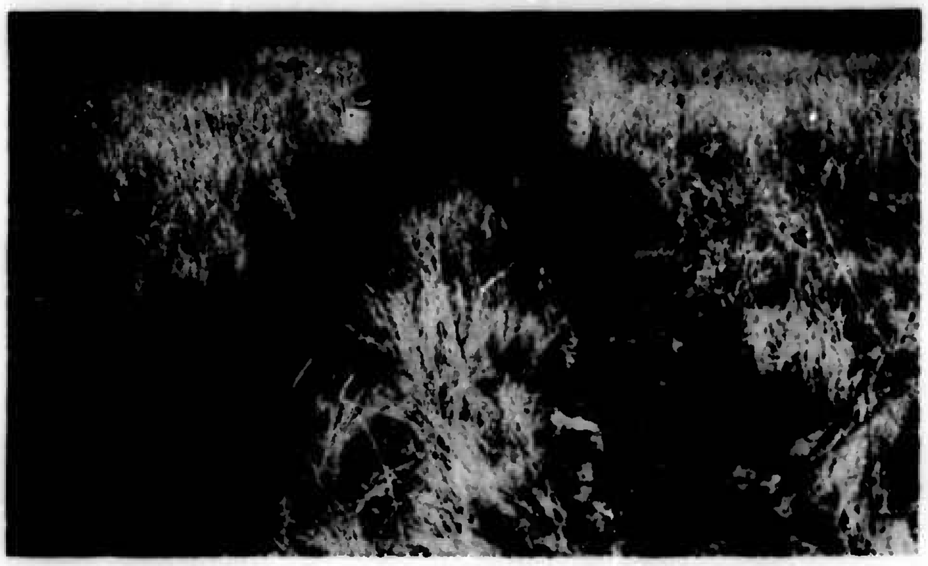
37. Tests with the 1/4-ton M151 truck (modified). Seven tests, two at Ft. Eustis and five at Ft. Lee, were conducted with this vehicle.

RCI-vehicle performance relations are shown in plate 1i. Four tests resulted in immobilizations and three resulted in the vehicle completing 50 passes. Examination of the data showed that the RCI of the 3- to 9-in. layer best correlated with vehicle performance; hence it was designated as the critical layer. In test 3 on an RCI of 24, the vehicle had considerable difficulty completing 50 passes (see fig. 16); however, the surface of the test lane was spotted with areas of vegetation and bare soil, and the vehicle encountered difficulty in holes which developed between areas of vegetation. In test 10 on an RCI of 24, the vehicle completed 50 passes with ease. In test 18 on an RCI of 22, the vehicle had difficulty completing 50 passes; therfore, the experimental VCI was estimated to be 23.

38. Tests with the 1/2-ton M274 carrier. RCI-vehicle performance relations are shown in plate 1j. Ten tests were conducted; six ended with the vehicle immobilizing before completion of 50 passes and four ended with the vehicle completing 50 passes or more. Two of the immobilization tests (35 and 37) were conducted in an area with free surface water, and the first-pass immobilizations were a result of low surface traction capacity rather than low bearing capacity, since the vehicle sank only 3 to 4 in. In test 35 the vehicle was able to back out of the test lane without assistance although it could not go forward. In test 37, the vehicle was able to back out of the test lane with some assistance (by pushing). Test 34 on soil similar to that of the two tests described above further supports the fact that low surface shear strength rather than low bearing strength of the critical layer may have caused the immobilizations. In this test, the vehicle could not go forward because of wheel slip on three occasions on the first pass. On each occasion, the vehicle was allowed to back up a few feet and then go forward again. After completion of the first pass in this manner, traffic was continued, and the vehicle completed 50 passes with no further difficulties.

39. After examination of plate 1j and other data, it was concluded that the 3- to 9-in. layer was the critical layer and that, with exclusion of tests 35 and 37 for reasons previously explained, the experimental VCI should be 20 for safe completion of 50 passes.

a. Test lane after 10 passes



b. During traffic, pass 21

c. Cutaway showing root structure in rut after 50 passes

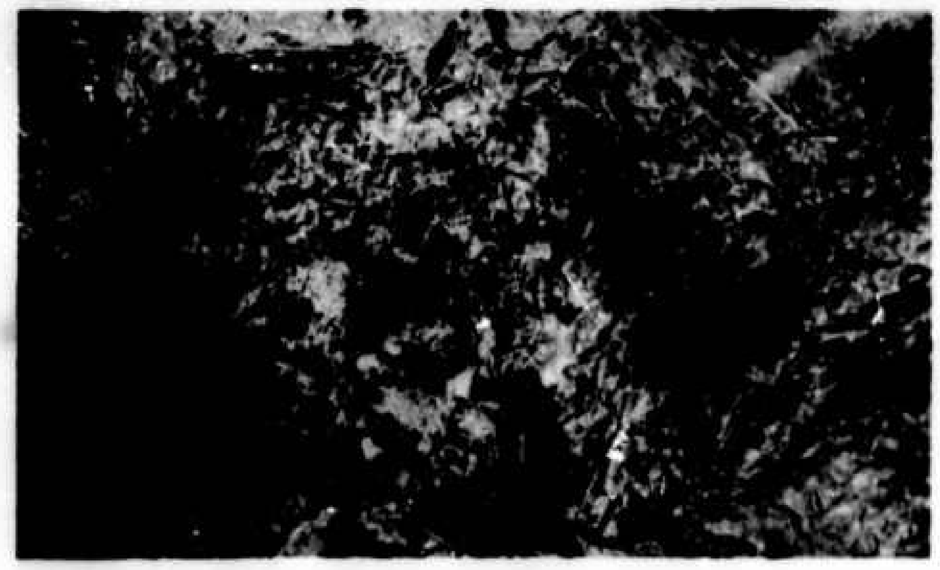


Fig. 16. Test 3, 1/4-ton M151, modified with low-pressure pneumatic tires, Ft. Eustis test area

PART III: REVISION OF MOBILITY INDEX FORMULA

40. The original mobility index formula and the revised mobility index formula developed herein are shown in Appendix A. This part of the report discusses data used in the development of the revised formula, the revised formula, a statistical analysis of both formulas, and finally the validity of the revised formula.

Data Used in Development of Revised Formula

41. Data used in development of the revised formula were limited to the vehicle test program reported herein and to other test programs in which sufficient testing was performed to determine experimentally the VCI for each vehicle.

Data from this report

42. The analysis of test results from Part II of this report produced experimental VCI's as follows:

Vehicle	Experimental VCI
16-ton XM438E2 with chains	60
16-ton XM438E2 without chains	62
Tournadozer	60
Bucket loader	50
1-1/2-ton power wagon modified	42
3/4-ton M37 truck empty	50
3/4-ton M37 truck loaded	58
Willys station wagon	50
1/4-ton M151 truck modified	23
1/2-ton M274 carrier	20

Data from other field test programs

43. Vehicles tested, experimental VCI's, and data sources from other field programs that were used in revision of the MI formula are listed below:

Vehicle	Experimental VCI	Data Source (See Literature Cited)
Electric digger	185	5
Log stacker	150	5

(Continued)

Vehicle	Experimental VCI	Data Source (See Literature Cited)
6-ton truck, 6x6	75	7
4-ton truck, 6x6	65	7
2-1/2-ton truck, 6x6	70	7
5-ton XM520 GOER with 15.00-34 tires	63	3
5-ton XM520 GOER with 18.00-26 tires	57	3
2-ton Meili Flex-Trac, 4x4	52	8
2-ton Meili Flex-Trac, 6x6	40	8
Gama goat	37	9

44. Pertinent data for the above-listed vehicles are given in table 3. It is worth noting that the 6-, 4-, and 2-1/2-ton trucks were three of the vehicles used in developing the original MI formula. In TM 3-240, Eighth Supplement, a cone index range was listed for these three vehicles, and the high value of the range was selected as the experimental VCI for purposes herein. For example, for the 6-ton truck, the cone index range was 65 to 75, and 75 was selected.

Revised Formula

45. The procedure for revising the original formula was primarily one of trial and error with some guidance from recent findings in laboratory studies.[10] Trial-and-error adjustments were made of vehicle factors and constants that composed the original formula until prediction of VCI could be made that best fitted the experimental VCI of each vehicle listed in paragraphs 42 and 43. The revised formula, shown in Appendix A, used the same eight factors as the original formula; however, for some of the factors, the value of the factor differs. The revised formula still permits the use of the existing mobility index-vehicle cone index curve, as shown in plate A1, or the tabulation of the data from which the curve was derived as given in table A1. When the revised formula is compared with the original formula, it can be seen that the multiplier factor 0.6 and the constant +20 have been dropped. The +20 constant limited values

obtained by the original formula to 20 or greater, which in turn limited the VCI to 34 or greater.

Factors adjusted

46. In addition to eliminating the multiplier factor and the constant, the original formula was further revised by adjustment of the contact pressure factor, weight factor, and tire factor. Adjustments of these factors are discussed below.

47. Contact pressure factor. True contact pressure of moving wheels over soil is difficult to determine, since it varies with soil strength, tire pressure, speed, wheel slip, and possibly other elements. It has been recognized that contact pressure is probably the most important factor in evaluating soft soil performance of a given tire. Since the development of the original mobility index formula, tire configurations have changed; for example, for Terra-tires, low-profile tires, air bags, and others, rim diameter may be small when compared to the overall diameter of the tire. For the "standard" military tires, such as 9.00-20 and 11.00-20, the overall diameters can be closely approximated as twice the nominal width plus rim diameter, or twice the rim diameter, while for a Terra-tire 36x20-14R the overall diameter of 36 in. is roughly two and one-half times the rim diameter of 14 in. For the range of tires considered, the tire radius was more suitable than the rim diameter in determining the contact pressure factor. If the tire diameter cannot be measured, then for the standard military tires it can be approximated from nominal width and rim diameter, and for the Terra-tires it can be approximated from the tire size stamped on the tire by the manufacturer. The revised contact pressure factor is as follows:

Contact pressure factor

$$= \frac{\text{gross weight of vehicle, lb}}{\text{tire width, in.,} \times \frac{\text{outside diameter of tire, in.}}{2} \times \text{No. of tires}}$$

48. Weight factor. The weight factor was modified to use four

weight ranges and a weight factor equation for each range. The equations use actual weights (in kips) of the vehicles and the number of axles to determine the weight factor for the mobility index formula. The weight factor ranges and equations for each weight range for the revised formula are presented in Appendix A.

49. Tire factor. The tire factor was adjusted by addition of a constant in the numerator and is computed as follows:

$$\text{Tire factor} = \frac{10 + \text{tire width, in.}}{100}$$

50. The constant, 10, was used to decrease the effect of tire width on the overall mobility index. This constant was found to be necessary to correct for inclusion of Terra-tires and large construction-equipment-type tires, and was obtained by trial-and-error adjustment until the best value was obtained.

Factors not adjusted

51. The following factors remained unchanged: grouser factor, wheel-load factor, clearance factor, engine factor, and transmission factor.

Comparison of experimental and computed VCI's for original and revised formulas

52. Comparisons of experimental and computed VCI's are shown in table 4. In table 4 the vehicles have been assigned a number for convenience; the vehicle with the highest VCI is "1" and the vehicle with the lowest VCI is "20." Experimental VCI's ranged from 185 for vehicle 1 (LeTourneau electric digger) to 20 for vehicle 20 (1/2-ton M274 carrier); however, a gap in VCI data appears between VCI's of 150 and 75, indicating a need for further testing of vehicles with heavy wheel loads (expected to have VCI's within this range) to further test the applicability of the revised formula. Comparisons show that, generally, the original formula computed VCI's lower than the experimental VCI for the heaviest vehicles (vehicles 1 through about 9) and computed VCI's higher than experimental for the lightest vehicles (vehicles 10 through 20). The absolute average

VCI unit error of the original formula was 19.0 for all vehicles, and 8.2 excluding vehicles 1 and 2 which were greatly in error. VCI unit errors for the revised formula showed an absolute average of 3.6 for all vehicles, and of 3.2 excluding vehicles 1 and 2. In terms of percent error, the average for the original formula was 26.4% (range from 2.0% to 130.0%) and for the revised formula was 6.1% (range 0% to 14.5%). The revised formula showed percent error lower than the original formula percent errors for 16 of the 20 vehicles. Comparisons of the accuracy of the two formulas in estimating the VCI show the improvement of the revised formula over the original formula for the 20 vehicles investigated. The improvement is shown graphically in plate 2.

Statistical analysis and evaluation of mobility index formulas

53. Examination of the previous paragraph and table 4 shows that the revised formula produced a very low unit error and percent error when the computed is compared with experimental VCI values. These low deviations of VCI with the revised formula and the fact that the revised formula is as simple and straightforward as the original formula are sufficient evidence that the revised formula should be accepted and used for future computation of MI and VCI. To determine if improvement in predicting VCI could be made, a more complicated statistical analysis was performed on the factors of both the original and revised MI formulas to determine if statistically derived formulas could be produced that would improve the accuracy of VCI predictions. This analysis involved the use of a multiple linear regression technique wherein mobility index formulas were produced that considered the best interrelation of the eight vehicle factors in the formulas. Evaluation of the results of the statistical analysis was made in terms of VCI unit error, VCI percent error, multiple correlation coefficient (R^2), and standard error of regression equation. The details of the analysis and evaluation are given in Appendix B and results are given in the following paragraphs. The two multiple linear regression formulas may be compared with the original and revised simplified formulas in Appendix A.

54. Multiple linear regression formula based on factors in the original formula. Based on the eight factors in the original formula (paragraph 3, Appendix A), the multiple regression formula becomes

$$MI = 0.65X_1 + 26.34X_2 - 102.84X_3 - 201.80$$

where

$$X_1 = 0.60 \left[\frac{(1) \times (2)}{(3) \times (4)} \times (7) \times (8)\right] + 10$$

$$X_2 = 0.60 \left[(5) \times (7) \times (8)\right] + 10$$

$$X_3 = 0.60 \left[(6) \times (7) \times (8)\right]$$

55. Multiple linear regression formula based on factors in the revised formula. Based on the eight factors in the revised formula (paragraph 3, Appendix A), the multiple linear regression becomes

$$MI = 0.96X_1 + 1.28X_2 + 3.90X_3 - 3.97$$

where

$$X_1 = \left[\frac{(1) \times (2)}{(3) \times (4)}\right] \times (7) \times (8)$$

$$X_2 = (5) \times (7) \times (8)$$

$$X_3 = (6) \times (7) \times (8)$$

56. Comparisons of results of computing VCI's by the four formulas. Comparisons were made of experimental VCI's from table 4 and VCI's computed by the four mobility index formulas as follows:

	Vehicle Cone Index			
	Unit Error		Percent Error	
Formula	Absolute Average	Range	Absolute Average	Range
Original (Appendix A, paragraph 3)	19.0	1-132	26.4	2.0-130.0

(Continued)

Formula	Vehicle Cone Index			
	Unit Error		Percent Error	
	Absolute Average	Range	Absolute Average	Range
Original, regression (paragraph 54)	9.1	0-34	18.7	0-91.9
Revised (Appendix A, paragraph 3)	3.6	0-9	6.1	0-14.5
Revised, regression (paragraph 55)	3.2	0-7	6.1	0-20.0

57. The tabulation above shows that considerable improvement was made in the original formula merely by using the multiple regression equation, and that still further improvements were made by using the revised formula. The multiple regression form of the revised formula effected only a slight increase in average VCI prediction accuracy. Since the improvement of the revised multiple regression formula (paragraph 55) over the simplified formula (Appendix A, paragraph 3) is only slight, it is suggested that the simplified form be adopted, especially for field application.

Validity of Revised Formula

58. Results of tests with vehicles different from those used in revising the MI formula were used to check the validity of the revised formula. Individual test results considered were those wherein test data were insufficient to determine the experimental VCI. The following tabulation lists data source and vehicles; details are given in table 5 and graphical comparisons are shown in plate 3.

Vehicle	Data Source (See Literature Cited)
1/4-ton M38 truck, 4x4	11
2-1/2-ton M135 truck, 6x6	11
2-1/2-ton M34 truck, 6x6	11
5-ton M41 truck, 6x6	11
5-ton M62 wrecker, 6x6	11
3/4-ton M37 truck, 4x4	12
2-1/2-ton CCKW353 truck, 6x6	12

(Continued)

Vehicle	Data Source (See Literature Cited)
2-1/2-ton M47 truck, 6x6 (two gross weights)	12
5-ton M41 truck, 6x6	12
2-1/2-ton M34 truck, 6x6	13
2-1/2-ton M34 truck (mod No. 1), 6x6	13
2-1/2-ton M34 truck (mod No. 2), 6x6	13
2-1/2-ton M35 truck, 6x6	13
2-1/2-ton M35 truck (mod), 6x6	13
2-1/2-ton XM410 truck, 8x8	13
5-ton M54 truck, 6x6	13
5-ton M41 truck (mod), 6x6	13
5-ton scamp, 4x4	13
5-ton XM453E2 truck, 8x8	13
5-ton XM520 GOER, 4x4	13
8-ton XM520E1 GOER, 4x4	13
8-ton XM409E8 truck, 8x8	13
16-ton XM437E1 GOER, 4x4	13
3/4-ton XM408 truck, 6x6	14
1-1/2-ton FC170 truck, 4x4	14
8-ton XM520E1 GOER, 4x4	14
16-ton XM438E2 GOER, 4x4	14

59. In constructing plate 3 the computed VCI of each vehicle was plotted against the rating cone index of the critical soil layer for each test for that vehicle. Also in plate 3 is a 1-to-1 line that would indicate 100 percent accuracy if all go (nonimmobilization) tests plotted to the right of the line and all no go tests plotted to the left. Plate 3 shows that a good separation of go-no go tests was obtained. Of the 64 tests with 28 vehicles the revised mobility index formula predicted, on a go-no go basis, with 89.1 percent accuracy. Of the seven tests that plot on the incorrect side of the separation line, five tests (15, 40, 44, 49, and 56) plot within 12 RCI units of the line. Two tests (29 and 58) plot 84 and 25 RCI units on the incorrect side of the line. An examination of basic data showed test 29 to have been conducted on a silty sand (93% sand, 7% silt) in which the remolding test indicated no change in strength should occur with traffic (remolding index was 1+), but apparently a strength change did occur. Basic data for test item 58 was limited

in quantity but so were data for test items 47 through 60; therefore, a basis exists for elimination of test 29 as an outlier but not test 58. With elimination of test 29, accuracy of prediction becomes 90.5%.

PART IV: SUMMARY OF TEST RESULTS, AND RECOMMENDATIONS

Summary of Results

60. A summary of results of the test program reported herein is given below.

a. Field tests were sufficient to establish experimental VCI's for 10 vehicle types (paragraph 42) as follows:

Vehicle	VCI	Vehicle	VCI
16-ton XM438E2 with chains	60	3/4-ton M37 empty	50
16-ton XM438E2 without chains	62	3/4-ton M37 loaded	58
Tournadozer	60	Willys station wagon	50
Bucket loader	50	1/4-ton M151 truck mod	23
1-1/2-ton power wagon	42	1/2-ton M274 carrier	20

b. A revised MI formula was developed from the experimental VCI's listed above and experimental VCI's for ten other vehicles (paragraph 43). The accuracy of predicting VCI with the original and revised formulas is compared below:

	Vehicle Cone Index			
	Unit Error		Percent Error	
Formula	Absolute Average	Range	Absolute Average	Range
Original	19.0	1-132	26.4	2.0-130.0
Revised	3.6	0-9	6.1	0-14.5

c. A check on the validity of the revised formula using results from 63 tests with 28 vehicles (not used in development of revised formula) shows that the revised MI formula predicted, on a go-no go basis, with 90.5% accuracy (paragraph 59 and plate 3).

Recommendations

61. It is recommended that:

a. The revised formula be adopted for use in computing VCI's for self-propelled all-wheel-drive vehicles.

b. Field tests be conducted with a few vehicles with VCI's in the range between 75 and 150; very little experimental data exist for this range.

c. Further investigation be made to determine if data herein and the revised formula (perhaps modified) can be used to compute VCI requirements on some basis other than 50 passes.

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Table 1

Vehicle Data, Vicksburg and Virginia Tests

Vehicle	Test Area	Weights, lb			Wheel and Tire Description											
		Empty	Pay Load	Test Weight	Nominal Width in.	Rim Diam in.	Wheel Diam in.	No. of Tires	Inflation Pressure psi	Total Contact Area, sq in.*	Avg Contact Pressure, psi	Ply Rating	Ground Clearance in.	Brake Horsepower	Transmission
16-ton XM438E2 GOER, 4x4 tanker	Virginia	38,310**	None	38,310	29.5	25	74†	4	15	2756	13.9	16	30	285	Mechanical
Tournadozer, 4x4 tractor	Vicksburg	31,370	None	31,370	21	25	67††	4	20	1286	24.4	16	14	127	Hydraulic
5-ton forklift, 4x4 rough terrain	Virginia	30,625	None	30,625	16	24	56††	4	42	1052	29.1	12	16	99	Hydraulic
Bucket loader, 4x4 tractor	Vicksburg	13,815	None	13,815	14	24	52††	4	30	514	26.9	8	15	77	Hydraulic
1-1/2-ton W300 power wagon (modified‡), 4x4	Virginia	6,370	2860	9,230	18	16	46†	4	10	898	10.5	4	15	115	Mechanical
3/4-ton M37. 4x4 truck	Vicksburg	5,925	None 1500**	5,925 7,425	9	16	34††	4	30	188 232	31.6 32.0	8	11	78	Mechanical
Willys station wagon, 4x4	Vicksburg	3,650	None	3,650	7	15	29††	4	30	--	--	6	8	105	Mechanical
1/4-ton M151 (modified‡), 4x4 truck	Virginia	2,970	460	3,430	20	14	36†	4	5	611	5.6	4	12	61	Mechanical
1/2-ton M274, 4x4 carrier (mule)	Vicksburg	960	300**	1,260	7.5	10	25††	4	15	84	15.0	4	11.5	15	Mechanical

* Determined from tire prints on hard surface.
** Estimated.
† Measured
†† Computed (rim diameter plus twice tire width).
‡ Low-pressure pneumatic tires; all other tires were standard for the respective vehicles.

Table 2

Summary of Data and

Test Location	No.	Immobilization Yes or No	Immobilization Pass No.	Data Pass No.	Average Cone Index 0	3	6	9	12	15	18	21	24	30	36	Average Cone Index of Layers 0-6	3-9	6-12	9-15	12-18	Remolding Index of Layers 0-6	6-12	12-1
16-ton XM438E2 GOER, 4x4 Tanker, Test W																							
Fort Lee, Va.	26	Yes	1	0	43	66	49	49	81	128	169	216+	245+	261+	284	53	55	60	86	126	0.36	0.42	0.76
Fort Lee, Va.	27	Yes	1	0	95	94	72	75	92	112	156	190+	197+	264+	300+	87	80	80	93	120	0.47	0.38	0.77
				1																			
Fort Lee, Va.	28	Yes	2	0	64	98	75	70	76	85	128	192	248+	291+	288+	79	81	74	77	96	0.37	0.24	0.59
				1	63	44	30	28	52	84	132	202+	248+	277+	287+								
Fort Lee, Va.	29	No	50	0	66	88	71	110	194	238	260+	284+	297+	298+	298+	75	90	125	181	231+	0.34**	0.38	0.80
				1	70	57	56	38	144	203	236+	274+	288+	294+	294+								
				5	34	52	92	142	199	257+	282+	286+	289+	297+	300+								
				11	43	92	122	183+	247+	276+	282+	292+	297+	300+									
				50	84	136	186+	248+	280+	300+													
Fort Lee, Va.	30	No	50	0	90	83	84	118	183	240+	250+	296+	294+	298+	300+	86	95	128	180+	224+	0.34**	0.63	0.58
				1	56	41	54	108	166	240+	264+	284+	289+	290+	299+								
				2	29	64	104	147+	184+	242+	272+	288+	294+	300+									
				50	54	118	160	226+	269+	279+	296+	300+											
Fort Lee, Va.	31	Yes	6	0	60	74	70	92	120	157	202+	226+	244+	273+	292+	68	79	94	123	160+	0.34**	0.60	0.74
				1	54	57	50	66	112	176+	208+	228+	242+	264+	288+								
				5	21	54	80	127	147	178+	216+	267+	271+	286+	286+								
Fort Lee, Va.	32	Yes	4	0	60	100	81	84	110	156	198+	247+	252+	262+	278+	80	88	92	117	155+	0.34**	0.62	0.78
				1	66	38	30	38	82	144	200+	254+	286+	292+	296+								
Fort Lee, Va.	33	No	50	0	67	84	83	94	156	216+	272+	290+	295+	300+		78	87	111	155+	215+	0.34**	0.77	0.66
				1	68	50	50	69	122	200	267+	293+	297+	300+									
				5	33	48	77	142	218+	274+	292+	298+	300+										
				10	34	90	136	218+	266+	291+	298+	300+											
				50	85	159	225+	260+	266+	297+	300+												
16-ton XM438E2 GOER, 4x4 Tanker, Test We																							
Fort Lee, Va.	21	No	50	0	88	164	116	133	180	219+	255+	282+	290+	295+	296+	123	138	143	177	218+	0.34**	0.62	0.42
				1	82	118+	118+	140+	184+	216+	250+	280+	294+	298+	300+								
				10	33	61	72	79+	104+	131+	152+	159+	164+	170+	180+								
				25	54	92	103	143	196+	228+	244+	254+	254+	266+	274+								
				50	64	98	130	184+	234+	264+	282+	286+	286+	298+	300+								
Fort Lee, Va.	22	No	50	0	66	92	90	113	167	214	253+	274+	294+	300+		83	98	123	165	211+	0.34**	0.62	0.50
				1	62	97	78	91	140	156	236+	274+	294+	296+	296+								
				10	28	55	81	121	174+	218+	268+	294+	300+										
				50	44	102	150	236+	272+	291+	294+	298+	296+	300+									
Fort Lee, Va.	24	Yes	1	0	52	60	66	46	62	102	150+	210+	244+	270+	293+	59	57	58	70	105+	0.24	0.50	0.72
Fort Lee, Va.	25	Yes	2	0	46	68	62	53	77	116	152	228+	238+	281+	298+	59	61	64	82	115	0.38	0.56	0.48
Fort Lee, Va.	34	No	50	0	76	102	110	146	206+	266+	281+	290+	292+	296+	300+	96	119	154	206	251	0.34**	0.65	0.67
				1	66	68	59	110	177	235+	286+	300+											
				5	44	48	78	132	218+	267+	300+												
				10	36	72	105	178+	263+	288+	296+												
				50	74	146+	222+	275+	286+	298+	300+												
Fort Lee, Va.	35	Yes	4	0	88	94	88	116	160	216	256	274+	294+	290+	292+	90	99	121	164	211	0.34**	0.45	0.60
				1	79	56	41	79	162	236	286	296+	300+										
Tournadozer, 4x4 Tractor, Test																							
Vicksburg, Miss.	1	No	50	0	36	58	74	84	102	112	114	126	139	145	156	56	72	87	99	109	--	0.84	0.80
				1	65	80	94	106	111	112	120	132	143	156	158								
				10	72	76	94	120	134	136	158	161	160	167	180								
				30	64	75	104	136	164	191	218	232	247	260	269								
				50																			

(Continued)

Note: + indicates that at least one CI value greater than 300 was used in determining the average.
Underlined RCI's were used in analyses to determine VCI.
0, 3, 6, etc., in column headings indicate depths (in inches) at which CI's were measured. 0-6, 3-9, etc., indicate depths of soil layers.
* Ruts were measured after vehicle was retrieved.
** Remolding index was estimated from adjacent test areas.

A

Table 2

of Data and Test Results

...ing Index of Layers 6-12	12-18	Rating Cone Index of Layers 0-6	3-9	6-12	9-15	12-18	Moisture Content of Layers, % Dry Wt 0-6	6-12	12-18	Dry Density of Layers, pcf 0-6	6-12	12-18	Rut Depth in.	Remarks
...anker, Test Weight = 38,310 lb (With Chains)														
0.42	0.76	19	21	25	51	96	27.2	22.9	26.6	90.8	99.2	89.2	12.4*	Vehicle immobilized on 1st pass, but was able to extricate itself
0.38	0.77	41	34	30	54	92	39.9	26.2	23.5	75.7	95.0	101.7	-- 34.3	Vehicle immobilized on 1st pass, undercarriage dragging
0.24	0.59	29	24	18	32	57	26.0	20.0	20.6	88.4	100.4	103.2	-- --	Vehicle immobilized on 2d pass, undercarriage on ground
0.38	0.80	26	32	48	107	185+	22.1	20.0	18.3	96.2	100.0	108.0	-- 1.6 6.8 11.0 16.2	Some wheel slip occurred after about 32 passes; however, vehicle completed 50 passes but with some difficulty
0.63	0.58	29	46	81	108+	130+	28.0	23.8	24.7	90.4	99.5	100.5	-- 2.6 10.3 17.2	Vehicle was immobilized on 2d pass when wheels sank deep in a soft spot. Undercarriage was not dragging. After considerable maneuvering, vehicle was able to move forward through the test lane. Vehicle was able to continue traffic and complete 50 passes with no further difficulty
0.60	0.74	23	37	56	82	118+	25.1	17.7	23.0	86.3	98.5	99.2	-- 1.0 7.8	Vehicle wheels began slipping on 4th pass and vehicle was immobilized on 6th pass. Undercarriage was not dragging. Able to continue traffic with considerable difficulty and only by using "wagon-steering" action. Completed 10 passes, test was then halted
0.62	0.78	27	42	[illegible]	82	121+	30.9	21.1	25.9	--	--	--	-- 1.8	Vehicle immobilized on 4th pass in reverse but moved forward out of test lane. Reentered test lane going forward and was able to complete 5th pass by using "wagon-steering" action
0.77	0.66	27	49	85	112+	142+	25.3	18.4	22.9	--	--	--	-- 0.7 6.4 11.0 16.9	Vehicle wheels began slipping on 25th pass. Completed 50 passes with some difficulty
...ker, Test Weight = 38,310 lb (Without Chains)														
0.62	0.42	42	66	89	92	92+	24.4	25.5	26.0	98.1	98.3	93.4	-- 1.1 5.6 9.5 14.4	Test area covered with blade grass. Some wheel slip occurred after 32d pass, but vehicle completed 50 passes with very little difficulty
0.62	0.50	28	47	76	92	106+	31.0	22.0	25.1	87.2	102.2	98.4	-- 1.4 6.2 15.1	Vehicle wheels began slipping on 40th pass; however, vehicle completed 50 passes but with some difficulty. Undercarriage was not dragging
0.50	0.72	14	21	29	43	76	32.0	24.0	23.4	85.8	96.6	99.6	15.6*	Vehicle immobilized on 1st pass, undercarriage was dragging
0.56	0.48	22	29	36	43	55	28.8	27.8	24.0	86.9	86.0	98.6	--	Vehicle completed 1st pass with considerable difficulty. Immobilized on 2d pass, undercarriage was dragging
0.65	0.67	33	60	100	136	168	18.3	20.6	22.3	104.7	101.4	--	-- 0.6 4.3 7.9 14.2	Vehicle wheels began slipping after 20 passes, and vehicle had more trouble when traveling in reverse than in forward. Completed 50 passes with wheel slip throughout the entire test lane. Undercarriage was not dragging
0.45	0.60	31	40	54	85+	127	25.6	21.2	23.6	91.8	103.4	--	-- 1.0	Vehicle was immobilized on 4th pass when wheels slipped, but no undercarriage dragging occurred. It could not go forward or backward more than 4 to 6 ft. Vehicle was able to climb out of test lane by using its full "wagon-steering" action
...ractor, Test Weight = 31,370 lb														
0.84	0.80	--	--	73	81	87	61.9	45.9	40.2	60.1	74.0	79.4	-- 2.6 5.8 9.1 11.9	Vehicle began to drag on 33d pass. Completed 50 passes without considerable difficulty

(Continued)

B

Table 2 (Continued)

Test Location	No.	Immobilization Yes or No	Immobilization Pass No.	Data Pass No.	Average Cone Index 0	3	6	9	12	15	18	21	24	30	36	Average Cone Index of Layers 0-6	3-9	6-12	9-15	12-18	Remolding Index of Layers 0-6	6-12	12-18	R[illegible] 0-6
Tournadozer, 4x4 Tractor, Test Weight = 31																								
Vicksburg, Miss.	2	Yes	43	0	33	42	50	73	88	98	111	121	116	123	134	42	55	70	86	99	--	0.74	0.72	--
				1	59	64	77	90	107	117	130	139	136	149	160									
				10	63	66	78	107	126	140	156	180	204	222	242									
				20	60	60	84	114	140	164	184	204	221	236	249									
Vicksburg, Miss.	4	No	50	0	34	63	67	84	92	99	107	106	104	105	110	55	71	81	92	99	--	0.77	0.78	--
				1	76	79	82	90	97	103	96	96	93	94	100									
				10	86	78	90	108	122	120	117	114	112	112	122									
				50	64	70	97	125	134	150	158	163	178	196	216									
Vicksburg, Miss.	5	Yes	33	0	31	38	52	64	78	94	100	100	108	117	120	40	51	65	79	91	--	0.87	0.81	--
				1	75	66	82	98	104	105	109	120	128	133	151									
				10	65	63	74	84	88	92	89	82	88	94	102									
Vicksburg, Miss.	7	Yes	29	0	30	27	40	52	73	85	96	94	96	106	123	32	40	55	70	85	--	0.80	0.86	--
				1	48	52	67	73	82	79	78	80	86	101	126									
				10	47	54	78	101	108	103	100	112	130	130	139									
				29	42	70	102	124	122	152	168	189	207	232	245									
Vicksburg, Miss.	8	No	50	0	37	42	52	70	80	90	93	110	113	122	124	44	55	67	80	88	--	0.88	0.80	--
				1	72	68	82	89	86	86	98	105	106	112	128									
				50	70	66	87	108	142	126	140	158	173	204	228									
Vicksburg, Miss.	10	Yes	3	0	28	42	57	62	64	75	77	80	82	88	88	42	54	61	67	72	--	0.78	0.69	--
Vicksburg, Miss.	11	Yes	1	0	12	31	52	58	58	60	64	63	64	64	62	32	47	56	59	61	--	0.68	0.79	--
Vicksburg, Miss.	12		††	0	22	40	57	72	82	88	82	80	78	74	71	40	56	70	81	84	--	0.66	0.64	--
Vicksburg, Miss.	13	Yes	3	0	18	35	62	64	66	72	76	84	81	88	95	38	54	64	67	71	--	0.63	0.78	--
5-ton Forklift, Rough Terrain, Test Wei																								
Fort Lee, Va.	13	Yes	1	0	67	92	77	82	106	127	174	240+	206+	261+	267+	79	84	88	105	136	0.45	0.58	0.69	36
Fort Lee, Va.	14		††	0	94	112	96	69	92	140	176	230+	238+	270+	292+	101	92	86	100	136	0.37	0.46	0.78	37
Fort Lee, Va.	15	Yes	1	0	55	52	60	82	116	178+	244+	267+	281+	300+		56	65	86	125+	179+	0.33	0.36	0.42	18
Fort Lee, Va.	16	Yes	2	0	160	130	102	84	123	186	221+	245+	267+	266+	264+	131	105	103	131	177+	0.24	0.58	0.26	31
Fort Lee, Va.	17	Yes	6	0	124	150	137	119	95	140	179	223+	268+	300+		137	135	117	118	138	0.30	0.69	0.59	41
Bucket Loader, 4x4 Tractor, [illegible]st Weigh																								
Vicksburg, Miss.	23	No	50	0	21	41	57	72	79	85	86	96	103	117	128	40	57	69	79	83	0.75**	0.76	0.80	30
				1	38	58	66	62	74	72	85	96	[illegible]	117	120									
				10	48	70	86	92	88	88	88	94	102	105	117									
				50	42	68	86	100	108	116	113	120	124	153	178									
Vicksburg, Miss.	24	No	50	0	17	42	50	61	73	89	98	100	106	111	112	36	51	61	74	87	0.75**	0.72	0.81	27
				1	36	58	72	78	89	92	86	88	98	103	116									
				10	40	79	84	92	101	97	97	106	116	120	140									
				50	30	64	87	101	106	113	114	112	120	142	149									
Vicksburg, Miss.	32	No	50	0	24	36	42	51	64	70	80	84	84	98	109	34	43	52	62	71	0.75**	0.78	0.79	26
				1	40	52	58	62	66	70	74	71	76	82	86									
				10	43	53	75	90	95	100	101	106	118	136	151									
				50	29	50	68	73	95	124	146	160	182	214	231									
Vicksburg, Miss.	40	Yes	3	0	10	30	44	51	44	48	52	54	68	80	72	28	42	46	48	48	0.83	0.74	0.60	23
Vicksburg, Miss.	45	Yes	1	0	6	29	44	40	27	31	36	46	54	78	86	26	38	37	33	31	0.64	0.69	0.63	17
Vicksburg, Miss.	46	Yes	5	0	17	54	58	46	46	50	56	66	68	70	75	43	53	50	47	51	0.75**	0.82	0.71	32

(Continued)

* Ruts were measured after vehicle was retrieved.
** Remolding index was estimated from adjacent test area.
† One-pass rut depth.
†† See remarks column.

A

Table 2 (Continued)

Remolding Index of Layers 0-6	6-12	12-18	Rating Cone Index of Layers 0-6	3-9	6-12	9-15	12-18	Moisture Content of Layers, % Dry Wt 0-6	6-12	12-18	Dry Density of Layers pcf 0-6	6-12	12-18	Rut Depth in.	Remarks
ractor, Test Weight = 31,370 lb (Continued)															
	0.74	0.72	--	--	52	63	71	75.4	52.9	38.9	48.4	68.0	77.3	-- 4.6 10.1 13.0	Vehicle began to drag on 14th pass, slip occurred on 29th pass, vehicle was immobilized on 43d pass
	0.77	0.78	--	--	62	72	77	66.4	48.3	37.7	57.0	68.2	75.2	-- 3.1 6.3 11.5	Vehicle started to drag on 36th pass, dragged entire test lane on 49th pass, completed 50 passes with no serious difficulty
	0.87	0.81	--	--	57	66	74	64.8	53.0	41.0	55.7	64.8	72.9	-- 4.4 9.9	Vehicle started to drag on 10th pass, dragged entire test lane on 23d pass, began to slip on 30th pass, immobilized on 33d pass traveling forward
	0.80	0.86	--	--	44	58	73	75.0	56.6	40.8	53.2	65.0	70.6	-- 5.0 10.2 15.3	Vehicle began to drag on 12th pass, dragged entire lane on 18th pass, began to slip on 25th pass, immobilized on 29th pass
	0.88	0.80	--	--	59	67	70	59.6	55.3	42.7	62.5	39.4	72.1	-- 4.7 15.3	Vehicle began dragging on 20th pass, dragged entire test lane on 32d pass. Vehicle was immobilized outside of test lane after 49th pass, but was pushed back into test lane with a D7 caterpillar. Vehicle completed 50th pass with difficulty
	0.78	0.69	--	--	48	50	50	--	--	--	--	--	--	--	Vehicle immobilized on 3d pass with undercarriage dragging, and could not extricate itself. Free water in right rut but none in left. It is believed that the free water contributed to the immobilization
	0.68	0.79	--	--	38	44	48	83.4	60.9	47.2	52.0	63.8	73.8	--	Vehicle immobilized on 1st pass with undercarriage dragging. Data taken on each side of vehicle at point of immobilization
	0.66	0.64	--	--	46	53	54	79.0	70.3	51.6	52.5	57.9	68.4	--	Vehicle completed one pass. No other traffic attempted
	0.63	0.78	--	--	40	47	55	76.7	57.4	42.7	54.2	65.3	77.5	--	Vehicle immobilized on 3d pass with undercarriage dragging
Rough Terrain, Test Weight = 30,625 lb															
[illegible]	0.58	0.69	36	44	51	67	94	35.7	25.1	23.2	79.9	99.5	104.0	--	Vehicle immobilized on 1st pass as it sank suddenly and undercarriage started dragging
[illegible]	0.46	0.78	37	39	40	62	106	30.8	22.9	23.4	88.5	97.0	102.2	3.1†	Vehicle completed one pass with some difficulty. Test halted because of rain
[illegible]	0.36	0.42	18	22	31	49+	75+	30.8	25.8	27.0	88.4	97.7	95.7	--	Vehicle immobilized on 1st pass, undercarriage dragging
[illegible]	0.58	0.26	31	43	60	55	46+	27.2	24.0	40.4	91.3	93.5	75.6	5.5†	Vehicle immobilized on 2d pass, undercarriage dragging
[illegible]	0.69	0.59	41	68	81	76	81	22.2	21.0	29.6	97.6	100.6	91.9	12.0*	Vehicle immobilized on 6th pass, undercarriage dragging
4x4 Tractor, Test Weight = 13,815 lb															
[illegible]**	0.76	0.80	30	43	52	62	66	70.6	46.7	45.5	56.0	70.6	75.6	-- 2.2 5.8 11.6	Vehicle completed 50 passes without difficulty. Tree roots in test lane may have enabled the vehicle to complete test
[illegible]**	0.72	0.81	27	38	44	56	70	69.8	48.0	41.6	56.3	71.1	76.6	-- 3.0 7.6 14.2	Vehicle began to drag on 33d pass. Completed 50 passes with extreme difficulty
[illegible]**	0.78	0.79	26	32	40	48	56	77.4	52.0	46.2	51.2	70.2	73.6	-- 3.3 9.4 18.0	Vehicle began to drag on 17th pass. Completed 50 passes; however, extremely high slippage occurred on the last few passes
[illegible]	0.74	0.60	23	33	34	32	29	64.2	60.8	45.6	59.6	64.2	73.8	--	Vehicle immobilized on 3d pass with undercarriage dragging. Data were taken in undisturbed soil near point of immobilization
[illegible]	0.69	0.63	17	25	26	22	20	57.3	64.4	45.6	67.3	61.4	75.4	14.7*	Vehicle immobilized on 1st pass while attempting to enter the test lane. Data were taken in undisturbed soil near point of immobilization.
[illegible]**	0.82	0.71	32	40	41	36	36	58.2	62.7	49.2	65.0	62.2	67.2	4.5†	Vehicle immobilized on 5th pass with undercarriage dragging. Water table was about 4 in. below surface, could not extricate itself

(Continued)

B

Table 2 (Continued

Test Location	No.	Immobilization Yes or No	Immobilization Pass No.	Data Pass No.	Average Cone Index 0	3	6	9	12	15	18	21	24	30	36	Average Cone Index of Layers 0-6	3-9	6-12	9-15	12-18	Remolding Index of Layers 0-6	6-12	12-18
Bucket Loader, 4x4 Tractor, Test Weight																							
Vicksburg, Miss.	55	Yes	1	0	16	28	48	46	46	44	44	52	58	61	63	31	41	47	45	45	0.75**	0.74	0.53
Vicksburg, Miss.	56	Yes	35	0	20	32	42	57	76	90	96	96	90	98	106	31	44	58	74	87	0.75**	0.80	0.74
Vicksburg, Miss.	60	Yes	40	0	20	32	44	58	58	58	58	58	60	65	76	32	45	53	58	58	0.68	0.82	0.70
				1	31	49	59	62	59	61	60	66	68	74	86								
				10	24	54	74	77	91	96	98	92	88	98	110								
				40	26	49	73	103	126	139	142	155	173	176	193								
Vicksburg, Miss.	61	Yes	44	0	24	46	60	65	63	56	58	70	81	92	99	43	57	63	61	59	0.75**	0.69	0.67
				1	32	54	69	68	62	60	66	70	80	82	97								
				10	30	58	75	80	102	108	110	114	119	123	126								
				43	28	56	72	102	123	132	137	128	122	124	152								
Vicksburg, Miss.	62	No	50	0	32	74	82	82	82	76	80	82	82	89	101	63	79	82	80	79	0.75**	0.79	0.80
				1	76	86	90	92	90	88	90	93	95	107	118								
				50	74	74	78	89	100	118	138	150	173	191	218								
Vicksburg, Miss.	63	No	50	0	26	46	55	71	86	91	92	98	96	97	94	42	57	71	83	90	0.75**	0.79	0.78
				1	60	64	72	78	86	82	81	89	97	96	102								
				50	56	63	80	102	116	133	144	146	154	148	152								
Vicksburg, Miss.	77	Yes	11	0	24	30	36	52	64	62	62	64	60	60	60	30	39	51	59	63	0.75	0.80	0.76
				1	49	52	57	58	63	60	63	60	59	60	60								
				10	30	41	44	62	82	101	114	124	134	138	138								
1-1/2-ton Power Wagon (Modified), Te																							
Fort Eustis, Va.	2	Yes	8	0	20	72	58	54	69	91	102	101	101	96	103	50	61	60	71	87	0.44	0.31	0.41
				1	22	50	52	56	56	72	79	82	84	84	89								
Fort Lee, Va.	4	No	50	0	64	112	108	120	142	196	230+	282+	276+	292+	300+	95	113	123	153	188+	0.34**	0.38	0.63
				10	54	105	128	168	184	236+	278+	297+	299+	300+									
				50	60	101	130	178	218+	274+	285+	290+	296+	296+	297+								
Fort Lee, Va.	5	No	50	0	50	64	76	85	153	192	230+	258+	286+	294+	294+	63	75	105	143	192+	0.34**	0.46	0.44
				10	50	38	62	104	165	202+	256+	264+	283+	288+	291+								
				50	35	70	120	158	196+	252+	270+	285+	288+	294+	296+								
Fort Lee, Va.	6	No	50	0	58	91	76	96	158	209	236+	265+	292+	293+	294+	75	88	110	154	201+	0.34**	0.54	0.59
				10	50	37	56	116	172	214+	240+	269+	290+	284+	297+								
				50	42	84	132	178	214+	232+	258+	274+	283+	286+	292+								
Fort Lee, Va.	9	Yes	15	0	58	73	78	72	110	164	229+	268+	282+	290+	292+	70	74	87	115	168+	0.34**	0.46	0.65
				5	58	46	44	48	100	178	250+	285+	295+	300+									
				8	63	32	39	68	108+	170+	206+	239+	259+	292+	298+								
				14	50	28	41	74	128	182+	228+	264+	266+	300+									
Fort Lee, Va.	11	Yes	8	0	50	60	43	48	74	109	152	196+	221+	260+	290+	51	50	55	77	112	0.40	0.53	0.88
				2	47	36	26	39	76	132	180+	222+	256+	284+	298+								
Fort Lee, Va.	12	No	50	0	75	84	88	80	118	157	197+	202+	248+	262+	274+	82	84	95	118	157+	0.33	0.46	0.61
				10	56	46	64	94	146	192+	220+	256+	263+	260+	286+								
				50	24	56	111	150	197+	240+	272+	288+	294+	300+									
Fort Lee, Va.	23	Yes	11	0	62	76	66	56	70	92	133	192+	235+	266+	289+	68	66	64	73	98	0.29	0.50	0.83
				1	60	56	54	50	60	58	126	186+	220+	260+	277+								
				10	32	28	30	46	79	118	179+	225+	242+	271+	280+								
Camp Pendleton, Va.	55	No	50	0	31	[illegible]	80	105	124	122	101	89	96	108	104	56	81	103	117	116	0.45	0.55	0.52
				1	26	57	76	110	124	120	111	96	88	96	105								
				5	26	43	74	99	112	122	97	89	87	96	98								
				25	20	56	104	125	122	100	84	98	89	102	110								
				50	26	70	112	145	120	105	86	93	99	109	117								
Camp Pendleton, Va.	56	Yes	38	0	25	102	55	65	70	72	65	68	75	115	195	61	[illegible]	63	69	69	--	0.58	--
				5	15	38	68	52	82	65	62	59	80	145	238								
				10	10	58	62	92	95	68	60	100	102	142	230								
				25	10	48	45	45	88	102	72	110	192+	230	300+								

(Continued)

** Remolding index estimated from adjacent test areas.

A

Table 2 (Continued)

...ding Index of Layers 6-12	12-18	Rating Cone Index of Layers 0-6	3-9	6-12	9-15	12-18	Moisture Content of Layers, % Dry Wt 0-6	6-12	12-18	Dry Density of Layers, pcf 0-6	6-12	12-18	Rut Depth in.	Remarks
...ctor, Test Weight = 13,815 lb (Continued)														
0.74	0.53	23	31	35	29	<u>24</u>	47.7	63.4	72.6	87.8	61.0	48.6	--	Vehicle towed into test lane with weasel, could not travel without aid of weasel, immobilized on 1st pass. Undercarriage did not drag
0.80	0.74	23	33	<u>46</u>	57	64	75.0	53.0	41.5	51.7	62.2	73.9	--	Some evidence of root structure helping to support vehicle on 8th pass. Vehicle dragging on 10th pass. No level and rod available for rut measurement. High slippage on 25th pass, immobilized on 35th pass
0.82	0.70	22	34	43	44	<u>41</u>	74.8	50.6	57.4	53.1	65.9	62.2	-- 4.4 11.0 14.4	Vehicle began to drag on 13th pass, immobilized on 40th pass. Could not extricate itself
0.69	0.67	32	43	43	41	<u>40</u>	76.8	51.3	59.4	52.4	69.6	63.8	-- 4.4 10.5 19.4	Vehicle began to drag on 12th pass, immobilized on 44th pass traveling in reverse. Vehicle was able to extricate itself in forward
0.79	0.80	47	59	65	64	<u>63</u>	66.2	44.2	49.0	58.6	76.4	72.0	-- 1.6 10.0	Vehicle completed 50 passes with ease
0.79	0.78	32	43	<u>56</u>	65	70	69.2	47.2	45.8	56.7	66.9	73.9	-- 3.2 13.5	Vehicle began to drag on 45th pass, completed 50 passes with wheel slips occurring
0.80	0.76	[illegible]	30	<u>41</u>	46	48	78.3	57.0	58.1	51.4	64.6	62.8	-- 5.4 18.4	Vehicle immobilized on 11th pass traveling forward, undercarriage dragging
...gon (Modified), Test Weight = 9400 lb														
0.31	0.41	22	23	<u>19</u>	26	36	107.4	58.0	30.6	40.0	65.8	92.8	-- 0.7	Vehicle was immobilized on 8th pass as deep holes developed on right side of test lane. Rut depth at point of immobilization was approximately 1.5 ft
0.38	0.63	32	41	<u>47</u>	76	118+	45.6	26.8	26.3	75.0	95.0	107.8	-- 1.2 5.5	Vehicle completed 50 passes with ease
0.46	0.44	21	30	<u>48</u>	64	84+	29.4	22.5	23.0	90.7	101.2	102.4	-- 2.5 12.0	Vehicle wheels began slipping on 42d pass; however, vehicle completed 50 passes with a little difficulty. Undercarriage did not drag at any time
0.54	0.59	26	35	<u>59</u>	86	119	30.5	22.6	21.9	89.4	102.9	106.0	-- 1.7 9.0	Vehicle completed 50 passes with ease
0.46	0.65	24	30	<u>40</u>	64	109+	29.6	26.0	22.6	87.8	93.3	101.2	-- 1.4 1.9 5.2	Vehicle immobilized on 15th pass when wheels began to slip. Undercarriage did not drag at any time
0.53	0.88	20	23	<u>29</u>	54	99	34.1	20.8	24.2	76.2	100.4	100.6	-- 1.7	Vehicle immobilized on 6th pass when it could not negotiate a root across the rut. Vehicle was retrieved and root removed, and vehicle was again immobilized on 8th pass when the undercarriage began to drag
0.46	0.61	27	34	<u>44</u>	64	96	30.4	23.6	27.6	86.2	98.2	92.2	-- 1.1 8.6	Vehicle completed 50 passes with ease
0.50	0.83	20	26	<u>32</u>	48	83	44.4	20.6	21.4	71.3	101.0	106.1	-- 0.5 4.2	Vehicle immobilized on 11th pass, retrieved, but immobilized on 12th pass when back axle dragged ground
0.55	0.52	25	40	<u>57</u>	63	60	61.8	21.1	24.3	60.2	104.2	100.2	-- 1.3 1.8 4.3 6.7	Vehicle completed 50 passes with ease
0.58	--	--	--	<u>37</u>	--	--	22.5	22.9	19.1	100.0	102.3	--	-- 3.1 4.9 7.1	Test conducted on silty sand beach area. Ruts began to develop on 1st pass, and after 10 passes, wheels were pushing mud out of ruts. Some wheel slip on 29th pass and undercarriage began to drag on 33d pass. Vehicle became immobilized on 38th pass. Data listed are for station of immobilization

(Continued)

Test Location	No.	Immobilization Yes or No	Immobilization Pass No.	Data Pass No.	Average Cone Index 0	3	6	9	12	15	18	21	24	30	36	Average Cone Index of Layers 0-6	3-9	6-12	9-15	12-18	Remolding Index of Layers 0-6	6-12	12-18	Rating 0-6	3-9
1-1/2-ton Power Wagon (Modified), Test Weight = 9																									
Camp Pendleton, Va.	57	Yes	4	0	32	40	55	50	62	70	70	105	148	192	280	42	48	56	61	67	0.85	0.62	0.52	36	36
				3	8	15	28	30	50	152	185+	200+	225+	275+	300+										
3/4-ton M37, 4x4 Truck, Test Weight =																									
Vicksburg, Miss.	19	No	56	0	24	61	66	78	87	92	100	102	109	124	135	50	68	77	86	93	0.77**	0.89	0.80	38	51
				1	68	80	78	82	85	82	92	82	78	95	120										
				10	70	80	80	85	75	82	68	82	72	65	125										
				56	57	79	91	78	80	84	80	84	96	104	114										
Vicksburg, Miss.	20	Yes	55	0	24	38	49	64	82	92	98	102	111	115	134	37	50	65	79	91	0.77**	0.82	0.81	28	38
Vicksburg, Miss.	21	Yes	37	0	15	25	35	55	71	81	88	84	86	82	88	25	38	54	69	80	0.77**	0.78	0.81	19	28
				1	40	48	58	66	69	78	90	100	99	105	116										
				10	30	55	63	62	68	72	74	75	81	96	100										
				37	24	60	74	80	92	98	102	112	120	132	138										
Vicksburg, Miss.	22	No	50	0	20	38	50	64	76	90	88	94	100	114	128	36	51	63	77	85	0.75**	0.77	0.86	27	38
				1	48	54	57	69	80	80	84	96	104	110	131										
				10	40	70	80	80	76	81	83	88	92	102	116										
				50	30	70	88	83	82	90	96	98	102	112	126										
Vicksburg, Miss.	30	No	50	0	22	44	48	56	63	73	80	89	88	96	103	38	49	56	64	72	0.75**	0.75	0.74	28	37
				1	42	52	52	56	62	72	75	84	86	92	108										
				10	44	66	71	70	68	72	80	88	90	98	126										
				50	40	72	88	92	90	91	96	94	101	121	144										
Vicksburg, Miss.	31	No	50	0	27	46	48	66	67	73	75	80	84	98	114	40	53	60	69	72	0.75**	0.76	0.74	30	40
				1	46	56	56	60	70	72	75	80	88	92	114										
				10	40	66	74	72	68	70	78	83	86	98	115										
				50	39	65	87	94	93	92	96	101	114	118	134										
Vicksburg, Miss.	33	Yes	11	0	23	30	50	56	64	66	71	74	78	80	87	34	45	57	62	67	0.75**	0.74	0.77	26	34
				1	40	44	50	62	67	75	78	84	79	81	87										
				10	38	59	63	55	61	64	70	72	75	80	84										
Vicksburg, Miss.	39	Yes	1	0	6	22	44	49	45	36	36	45	52	--	--	24	38	46	43	39	0.81	0.72	0.74	19	29
				1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Vicksburg, Miss.	54	No	50	0	28	28	36	53	61	66	68	76	85	92	96	31	39	50	60	65	0.86	0.88	0.86	27	34
				1	46	50	55	61	62	64	71	76	81	87	86										
				10	39	53	62	63	60	60	61	63	69	64	67										
				50	29	50	56	64	63	64	63	73	74	79	88										
Vicksburg, Miss.	64	Yes	18	0	22	22	30	46	59	55	50	56	50	56	64	25	33	45	53	55	0.83	0.79	0.62	21	27
				1	36	40	42	39	44	48	47	55	54	68	68										
				10	28	56	50	52	58	64	69	74	72	76	76										
				17	28	48	53	46	53	58	60	62	70	78	86										
3/4-ton M37, 4x4 Truck, Test Weight = 7																									
Vicksburg, Miss.	65	Yes	1	0	22	27	32	39	48	58	58	63	60	60	62	27	33	40	48	55	0.70	0.70	0.66	19	23
				1	25	40	50	50	52	58	58	61	60	73	76										
Vicksburg, Miss.	66	Yes	38	0	28	48	51	60	62	70	76	83	92	106	108	42	53	58	64	69	0.80	0.79	0.80	34	42
				1	45	60	65	64	63	72	80	91	104	106	107										
				10	46	72	84	82	79	86	98	99	112	130	144										
				38	42	58	80	90	102	112	121	134	144	154	162										
Vicksburg, Miss.	67	Yes	18	0	35	73	74	74	74	78	83	90	96	109	115	61	74	74	75	78	0.56	0.60	0.76	34	43
				1	51	79	79	70	71	76	76	83	86	108	112										
				10	41	73	78	72	74	84	92	104	108	104	106										
				17	42	75	81	56	90	92	95	115	115	128	136										

(Continued)

** Remolding index estimated from adjacent test areas.

A

e 2 (Continued)

Index of Layers .12	Index of Layers 12-18	Rating Cone Index of Layers 0-6	3-9	6-12	9-15	12-18	Moisture Content of Layers, % Dry Wt 0-6	6-12	12-18	Dry Density of Layers, pcf 0-6	6-12	12-18	Depth in.	Remarks
ied), Test Weight = 9400 lb (Continued)														
.62	0.52	36	36	35	35	35	--	--	--	--	--	--	-- 11.5	Same test area as preceding test. Some wheel slip on 3d pass, and vehicle was immobilized on 4th pass when left side sank rather suddenly. Data listed are for station of immobilization
Truck, Test Weight = 5925 lb														
.89	0.80	38	51	68	72	74	69.6	55.9	51.1	54.9	64.1	65.8	-- 1.6 3.8 9.4	Vehicle operated as 4x2 for complete test, completed 56 passes with ease, did not drag
.82	0.81	28	38	53	65	74	64.8	48.4	43.0	55.4	71.6	70.2	--	Vehicle began operating as 4x2, started slipping and dragging on 10th pass, immobilized on 16th pass. Front drive engaged and test continued, completed 50 passes with extreme difficulty, immobilized on 55th pass. Heavy rain occurred during time test was conducted
.78	0.81	19	28	42	55	65	68.8	51.0	41.6	56.5	70.7	77.7	-- 3.6 8.9 13.2	Vehicle began operating as 4x2, experienced high slip on 1st pass. Vehicle started to drag on 13th pass going forward. Excessive slip occurred over the entire test lane on 17th pass. Vehicle immobilized on 20th pass traveling in reverse. Front drive engaged and test continued. Immobilized on 37th pass traveling forward, was able to extricate itself in reverse, test stopped
.77	0.86	27	38	48	63	73	65.9	47.3	46.6	59.0	69.0	69.2	2.3 7.4 12.5	Vehicle began operating as a 4x2, started to drag on 16th pass. Experienced excessive slip on 20th pass, immobilized on 28th pass traveling in reverse. Front drive engaged and test continued with vehicle operating as a 4x4. Completed 50 passes without becoming immobilized; however, it was having extreme difficulty
.75	0.74	28	37	42	47	53	66.7	47.1	47.0	57.9	70.8	72.6	-- 2.0 6.5 11.9	Vehicle began operating as a 4x2, started dragging on 19th pass, immobilized on 40th pass. Front drive engaged and test continued. Completed 50 passes with extreme difficulty
.76	0.74	30	40	46	52	53	64.8	52.8	43.4	61.1	69.1	74.7	-- 1.9 6.0 11.3	Vehicle began operating as a 4x2, started to drag on 17th pass, immobilized on 40th pass. Front drive engaged and test continued. Completed 50 passes with ease
.74	0.77	26	34	42	47	52	70.9	60.8	51.5	53.2	62.8	[illegible]	-- 2.6 10.9	Vehicle began operating as a 4x2, immobilized on 2d pass. Front drive engaged and test continued. Vehicle started to drag on 8th pass. After 10-pass data were taken water flowed up through penetrometer holes. Vehicle immobilized on 11th pass
.72 --	0.74 --	19 --	29 --	33 --	31 --	29 --	76.1 --	67.0 --	59.1 --	55.1 --	60.4 --	65.6 --	-- 7.5	Vehicle immobilized on 1st pass. It is believed that the water in the ruts contributed to the immobilization. Free water in small depressions. Water table about 1 in. below the surface. After immobilization vehicle could not extricate itself; undercarriage did not drag
.88	0.86	27	34	44	52	56	70.1	48.6	52.5	53.9	70.2	68.0	-- 3.1 8.5 14.3	Vehicle began operating as a 4x2, began dragging on 15th pass. Vehicle tilted to left side, immobilized on 24th pass. Drive engaged and test continued. Vehicle completed 50 passes with extreme difficulty, swales and ridges in ruts apparently caused by root structure
.79	0.62	21	27	36	37	34	79.6	59.2	53.0	50.6	64.6	70.2	-- 3.9 11.5 14.2	30-ft test lane, data at 5-ft intervals. Vehicle completed 17 passes with extreme difficulty, immobilized on 18th pass, could not go forward or backward
Truck, Test Weight = 7425 lb														
.70	0.66	19	23	28	33	36	70.8	57.7	53.6	56.1	63.6	69.4	-- 8.2	Vehicle could not travel as a 4x2. As a 4x4 the vehicle was pulled into the test lane, traveled for 35 ft, and was immobilized
.79	0.80	34	42	46	51	55	71.4	44.6	53.7	53.6	74.8	66.8	-- 1.9 8.1 12.9	Vehicle could not travel as 4x2. Front drive engaged and test continued. Vehicle began to drag on 13th pass, began to slip on 25th pass, immobilized on 38th pass. Tree roots in ruts may have affected test results
.60	0.76	34	43	44	51	59	45.2	57.4	48.9	55.8	67.3	71.5	-- 1.8 8.1 10.3	Vehicle began operating as a 4x2, started dragging and slipping on 14th pass, immobilized on 18th pass. A layer of sand about 2 in. thick and located about 4 in. below the surface was present over the entire test lane

(Continued)

B

Test Location	No.	Immobilization Yes or No	Immobilization Pass No.	Data Pass No.	Average Cone Index 0	3	6	9	12	15	18	21	24	30	36	Average Cone Index of Layers 0-6	3-9	6-12	9-15	12-18	Remolding Index of Layers 0-6	6-12	12-18	0-6
																				3/4-ton M37, 4x4 Truck, Test Weight =				
Vicksburg, Miss.	68	No	50	0	30	59	66	72	80	78	79	84	88	106	114	52	66	73	77	79	0.85	0.76	0.82	44
				1	54	70	78	78	76	80	88	94	99	112	120									
				10	48	72	83	80	83	91	101	98	106	110	118									
				50	42	70	88	104	120	132	144	136	150	146	158									
Vicksburg, Miss.	79	Yes	1	0	8	35	51	40	40	40	45	51	58	--	--	31	42	44	40	42	0.84	0.80	0.80**	26
Vicksburg, Miss.	80	Yes	5	0	19	48	44	38	40	38	44	48	52	--	--	37	43	41	39	41	0.93	0.80	0.80**	34
																					Willys Station Wagon, Test Weig			
Vicksburg, Miss.	72	Yes	5	0	4	25	41	50	47	44	44	43	45	--	--	23	39	46	47	45	0.76	0.72	0.72	17
Vicksburg, Miss.	73	Yes	1	0	4	22	33	45	37	36	40	42	50	--	--	20	33	38	39	38	0.78	0.74	0.71	16
Vicksburg, Miss.	75	Yes	12	0	9	31	47	53	53	57	64	68	77	98	107	29	44	51	54	58	0.74	0.67	0.60	21
Vicksburg, Miss.	88	Yes	32	0	30	42	53	68	68	66	76	78	84	97	114	42	54	63	67	70	0.77**	0.74	0.67	32
				1	42	50	54	62	60	66	78	93	106	114	128									
				10	38	61	65	65	65	82	100	106	112	123	132									
				37	40	54	71	74	93	110	120	131	132	131	141									
Vicksburg, Miss.	89	Yes	48	0	32	45	54	64	65	69	83	94	105	114	124	44	54	61	66	72	0.80	0.76	0.76	35
				1	44	52	58	60	64	71	92	105	110	124	141									
				10	48	60	68	64	64	87	101	111	122	134	130									
				48	34	62	67	80	100	107	121	142	154	158	160									
Vicksburg, Miss.	90	Yes	14	0	32	59	66	60	64	66	78	89	99	108	110	52	62	63	63	69	0.77**	0.66	0.74	40
				1	44	64	74	58	64	74	84	102	107	111	123									
				10	42	66	72	68	73	92	100	110	122	124	133									
				14	39	50	60	62	72	85	104	114	116	117	122									
Vicksburg, Miss.	91	No	50	0	30	46	62	70	72	70	70	72	88	94	98	46	59	68	71	71	0.77**	0.78	0.79	35
				1	56	61	66	70	70	73	72	74	88	98	103									
				10	52	64	65	64	64	70	71	78	86	92	94									
				50	55	70	80	74	72	76	86	92	98	106	114									
																				1/4-ton M151, 4x4 Truck (Modified), Te				
Fort Eustis, Va.	1	Yes	27	0	12	46	45	43	52	59	68	81	92	102	100	34	45	47	51	60	0.34	0.40	0.31	12
				1	13	45	38	40	54	58	69	78	92	99	96									
				10	16	45	43	42	49	60	69	82	96	104	98									
Fort Eustis, Va.	3	No	50	0	21	44	44	49	61	76	85	86	83	90	100	36	46	51	62	74	0.46	0.60	0.46	17
				1	25	42	48	48	68	101	88	89	91	105	114									
				10	30	51	46	50	62	84	82	81	88	91	100									
				50	29	38	38	50	78	84	80	84	88	100	112									
Fort Lee, Va.	8	Yes	16	0	31	68	72	78	97	140	174	217+	236+	274+	287+	57	73	82	105	137	0.26	0.28	0.70	15
				5	29	52	60	69	90	115	155	210+	246+	268+	276+									
				10	23	46	51	69	94	130	196+	226+	250+	282+	294+									
				15	21	38	61	78	94	136	177	249+	290+	298+	300+									
Fort Lee, Va.	10	No	50	0	64	78	60	53	68	106	160	216+	242+	264+	284+	67	64	60	76	111	0.33	0.43	0.68	22
				5	67	80	64	60	84	142	200+	246+	251+	269+	279+									
				20	74	76	56	52	70	108	170	204+	231+	270+	289+									
				50	62	45	44	53	82	119	174+	206+	228+	260+	288+									

(Continued)

* Ruts measured after vehicle was retrieved.
** Remolding index estimated from adjacent test areas.

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le 2 (Con'.nued)

g Index of Layers 6-12	12-18	Rating Cone Index of Layers 0-6	3-9	6-12	9-15	12-18	Moisture Content of Layers, % Dry Wt 0-6	6-12	12-18	Dry Density of Layers pcf 0-6	6-12	12-18	Rut Depth in.	Remarks
, Test Weight = 7425 lb (Continued)														
0.76	0.82	44	53	55	61	65	63.0	46.8	46.4	61.0	74.0	71.4	-- 2.3 7.8 13.5	Vehicle began operating as a 4x4, began to drag on 14th pass, experienced heavy dragging on 19th pass, had extreme difficulty on 47th pass. Completed 50 passes with extreme difficulty
.80	0.80**	26	34	35	32	34	60.9	62.4	59.4	63.6	61.5	65.0	--	Vehicle operated as a 4x4, was immobilized on 1st pass, could not extricate itself. Undercarriage did not drag
0.80	0.80**	34	37	33	31	33	57.4	55.9	49.1	66.2	64.7	71.6	--	Vehicle operated as a 4x4, immobilized on 5th pass, undercarriage dragging. Vehicle could not extricate itself
Wagon, Test Weight = 3650 lb														
0.72	0.72	17	29	33	34	32	55.7	65.4	57.2	66.7	61.0	66.3	9.8*	Vehicle immobilized on 5th pass traveling forward, undercarriage dragging. Could not extricate itself. Operated as a 4x4
0.74	0.71	16	25	28	28	27	59.8	61.4	52.2	64.5	63.0	69.8	9.2*	Vehicle immobilized on 1st pass traveling forward, undercarriage dragging. Extricated itself in reverse but could not turn out of ruts. Operated as a 4x4
0.67	0.60	21	31	34	35	35	54.2	54.2	54.0	69.8	68.4	67.7	7.7*	Vehicle operated as 4x4, began dragging on 6th pass. Wheels began to slip on 8th pass. Vehicle immobilized on 12th pass, could not extricate itself
0.74	0.67	32	40	47	47	47	76.6	49.5	55.4	53.9	63.8	64.4	-- -- -- --	Vehicle completed one pass as 4x2, immobilized on 2d pass as 4x2. Front drive engaged and test continued. Vehicle began dragging on 11th pass, immobilized on 32d pass in reverse, extricated itself in forward, and continued back and forth, immobilized on 38th pass in reverse, extricated itself in forward, and was immobilized on 40th pass in reverse. Could not extricate itself
0.76	0.76	35	42	46	50	55	69.4	47.0	45.8	56.4	72.1	72.0	-- 1.4 4.6 10.5	Vehicle began operating as 4x2, began to drag on 18th pass, immobilized on 26th pass. Front drive engaged and test continued with vehicle operating as 4x4. Immobilized on 48th pass in reverse, extricated itself in forward
0.66	0.74	40	46	42	44	51	64.1	46.3	44.3	60.7	72.2	69.0	-- 0.8 4.4 6.6	Vehicle began operating as 4x2, began dragging on 14th pass, immobilized on 14th pass; also left rear-wheel housing was jammed with mud and would not turn. Front wheel drive was engaged but vehicle still could not move forward or backward. When towed out, the left rear wheel did not turn until the vehicle reached undisturbed soil
0.78	0.79	35	44	53	55	56	65.7	47.7	50.8	58.5	72.6	66.6	-- 1.2 3.6 8.0	Vehicle began operating as 4x2, started to drag on 25th pass, immobilized on 42d pass. Front drive engaged and test continued. Completed 50 passes with almost no difficulty. Wheels were not spinning at completion of 50 passes, but vehicle undercarriage was dragging throughout the entire length of test lane
ck (Modified), Test Weight = 3430 lb														
0.40	0.31	12	17	19	18	19	179.2	50.9	44.1	29.1	69.0	75.8	-- 0.2 0.8	Vehicle operated as 4x2 until immobilized on 10th pass with left-rear wheel in a hole that developed between mounds of grass. Continued test as 4x4 and immobilized on 27th pass with left-front wheel in a hole between grass mounds. Rut depth in hole was 1.2 ft. Cone indexes measured between grass mounds. Cone indexes in grass mounds were 150 to 250 at 2 to 3 in.
0.60	0.46	17	24	31	33	34	179.7	46.0	31.3	27.0	68.7	90.0	-- 0.1 0.5 3.6	Vehicle began having difficulty after 29 passes as holes formed between mounds of grass. Completed 50 passes with considerable difficulty. Cone indexes measured between grass mounds. Rut depths in holes were about 1.3 ft after 5 passes
0.28	0.70	15	20	23	51	96	28.2	21.4	27.6	90.4	102.2	100.6	-- 0.6 1.2 2.6	Test conducted in an area void of vegetation. Vehicle was immobilized on 16th pass but was able to extricate itself. Immobilized again on 19th pass. Vehicle undercarriage was not dragging on either immobilization. Maximum rut depth at point of immobilization was 0.68 ft after 15 passes
0.43	0.68	22	24	26	42	75	32.8	20.8	23.8	83.5	102.6	101.6	-- 0.5 0.8 1.4	Vehicle completed 50 passes with ease. 1-1/2-ton power wagon completed 12 passes in test lane and test vehicle again continued traffic. After 20 passes vehicle was having difficulty and became immobilized when front wheel could not climb over tree root in test lane. Rut depth approximately 0.95 ft at point of immobilization

(Continued)

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Test Location	No.	Immobilization Yes or No	Immobilization Pass No.	Data Pass No.	Average Cone Index 0	3	6	9	12	15	18	21	24	30	36	Average Cone Index of Layers 0-6	3-9	6-12	9-15	12-18	Remolding Index of Layers 0-6	6-12	12-18	R 0-6
3/4-ton M37, 4x4 Truck, Test Weight = 7																								
Vicksburg, Miss.	68	No	50	0	30	59	66	72	80	78	79	84	88	106	114	52	66	73	77	79	0.85	0.76	0.82	44
				1	54	70	78	78	76	80	88	94	99	112	120									
				10	48	72	83	80	83	91	101	98	106	110	118									
				50	42	70	88	104	120	132	144	156	150	146	158									
Vicksburg, Miss.	79	Yes	1	0	8	35	51	40	40	40	45	51	58	--	--	31	42	44	40	42	0.84	0.80	0.80**	26
Vicksburg, Miss.	80	Yes	5	0	19	48	44	38	40	38	44	48	52	--	--	37	43	41	39	41	0.93	0.80	0.80**	34
Willys Station Wagon, Test Weight																								
Vicksburg, Miss.	72	Yes	5	0	4	25	41	50	47	44	44	43	45	--	--	23	39	46	47	45	0.76	0.72	0.72	17
Vicksburg, Miss.	73	Yes	1	0	4	22	33	45	37	36	40	42	50	--	--	20	33	38	39	38	0.78	0.74	0.71	16
Vicksburg, Miss.	75	Yes	12	0	9	31	47	53	53	57	64	68	77	98	107	29	44	51	54	58	0.74	0.67	0.60	21
Vicksburg, Miss.	88	Yes	32	0	30	42	53	68	68	66	76	78	84	97	114	42	54	63	67	70	0.77**	0.74	0.67	32
				1	42	50	54	62	60	66	78	93	106	114	128									
				10	38	61	65	65	65	82	100	106	112	123	132									
				37	40	54	71	74	93	110	120	131	132	131	141									
Vicksburg, Miss.	89	Yes	48	0	32	45	54	64	65	69	83	94	105	114	124	44	54	61	66	72	0.80	0.76	0.76	35
				1	44	52	58	60	64	71	92	105	110	124	141									
				10	48	60	68	64	64	87	101	111	122	13[illegible]	130									
				48	34	62	67	80	100	107	121	142	154	158	160									
Vicksburg, Miss.	90	Yes	14	0	32	59	66	60	64	66	78	89	99	108	110	52	62	63	63	69	0.77**	0.66	0.74	40
				1	44	64	74	58	64	74	84	102	107	111	123									
				10	42	66	72	68	73	92	100	110	122	124	133									
				14	39	50	60	62	72	85	104	114	116	117	122									
Vicksburg, Miss.	91	No	50	0	30	46	62	70	72	70	70	72	88	94	98	46	59	68	71	71	0.77**	0.78	0.79	35
				1	56	61	66	70	70	73	72	74	88	98	103									
				10	52	64	65	64	64	70	71	78	86	92	94									
				50	55	70	80	74	72	76	86	92	98	106	114									
1/4-ton M151, 4x4 Truck (Modified), Test																								
Fort Eustis, Va.	1	Yes	27	0	12	46	45	43	52	59	68	81	92	102	100	34	45	47	51	60	0.34	0.40	0.31	12
				1	13	45	38	40	54	58	69	78	92	99	96									
				10	16	45	43	42	49	60	69	82	96	104	98									
Fort Eustis, Va.	3	No	50	0	21	44	44	49	61	76	85	86	83	90	100	36	46	51	62	74	0.46	0.60	0.46	17
				1	25	42	48	48	68	101	88	89	91	105	114									
				10	30	51	46	50	62	84	82	81	88	91	100									
				50	29	38	38	50	78	84	80	84	88	100	112									
Fort Lee, Va.	8	Yes	16	0	31	68	72	78	97	140	174	217+	236+	274+	287+	57	73	82	105	137	0.26	0.28	0.70	15
				5	29	52	60	69	90	115	155	210+	246+	268+	276+									
				10	23	46	51	69	94	130	196+	226+	250+	282+	294+									
				15	21	38	61	78	94	136	177	249+	290+	298+	300+									
Fort Lee, Va.	10	No	50	0	64	78	60	53	68	106	160	216+	242+	264+	284+	67	64	60	76	111	0.33	0.43	0.68	22
				5	67	80	64	60	84	142	200+	246+	251+	269+	279+									
				20	74	76	56	52	70	108	170	204+	231+	270+	289+									
				50	62	45	44	53	82	119	174+	206+	228+	260+	288+									

(Continued)

* Ruts measured after vehicle was retrieved.
** Remolding index estimated from adjacent test areas.

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Table 2 (Con' .nued)

lding Index of Layers		Rating Cone Index of Layers					Moisture Content of Layers, % Dry Wt			Dry Density of Layers, pcf			Rut Depth in.	Remarks
6-12	12-18	0-6	3-9	6-12	9-15	12-18	0-6	6-12	12-18	0-6	6-12	12-18		
ruck, Test Weight = 7425 lb (Continued)														
0.76	0.82	44	53	55	61	65	63.0	46.8	46.4	61.0	74.0	71.4	-- 2.3 7.8 13.5	Vehicle began operating as a 4x4, began to drag on 14th pass, experienced heavy dragging on 19th pass, had extreme difficulty on 47th pass. Completed 50 passes with extreme difficulty
0.80	0.80**	26	34	35	32	34	60.9	62.4	59.4	63.6	61.5	65.0	--	Vehicle operated as a 4x4, was immobilized on 1st pass, could not extricate itself. Undercarriage did not drag
0.80	0.80**	34	37	33	31	33	57.4	55.9	49.1	66.2	64.7	71.6	--	Vehicle operated as a 4x4, immobilized on 5th pass, undercarriage dragging. Vehicle could not extricate itself
ion Wagon, Test Weight = 3650 lb														
0.72	0.72	17	29	33	34	32	55.7	65.4	57.2	66.7	61.0	66.3	9.8*	Vehicle immobilized on 5th pass traveling forward, undercarriage dragging Could not extricate itself. Operated as a 4x4
0.74	0.71	16	25	28	28	27	59.8	61.4	52.2	64.5	63.0	69.8	9.2*	Vehicle immobilized on 1st pass traveling forward, undercarriage dragging. Extricated itself in reverse but could not turn out of ruts. Operated as a 4x4
0.67	0.60	21	31	34	35	35	54.2	54.2	54.0	69.8	63.4	67.7	7.7*	Vehicle operated as 4x4, began dragging on 6th pass. Wheels began to slip on 8th pass. Vehicle immobilized on 12th pass, could not extricate itself
0.74	0.67	32	40	47	47	47	76.6	49.5	55.4	53.9	63.8	64.4	-- -- -- --	Vehicle completed one pass as 4x2, immobilized on 2d pass as 4x2. Front drive engaged and test continued. Vehicle began dragging on 11th pass, immobilized on 32d pass in reverse, extricated itself in forward, and continued back and forth, immobilized on 38th pass in reverse, extricated itself in forward, and was immobilized on 40th pass in reverse. Could not extricate itself
0.76	0.76	35	42	46	50	55	69.4	47.0	45.8	56.4	72.1	72.0	-- 1.4 4.6 10.5	Vehicle began operating as 4x2, began to drag on 18th pass, immobilized on 26th pass. Front drive engaged and test continued with vehicle operating as 4x4. Immobilized on 48th pass in reverse, extricated itself in forward
0.66	0.74	40	46	42	44	51	64.1	46.3	44.3	60.7	72.2	69.0	-- 0.8 4.4 6.6	Vehicle began operating as 4x2, began dragging on 14th pass, immobilized on 14th pass; also left rear-wheel housing was jammed with mud and would not turn. Front wheel drive was engaged but vehicle still could not move forward or backward. When towed out, the left rear wheel did not turn until the vehicle reached undisturbed soil
0.78	0.79	35	44	53	55	56	65.7	47.7	50.8	58.5	72.6	66.6	-- 1.2 3.6 8.0	Vehicle began operating as 4x2, started to drag on 25th pass, immobilized on 42d pass. Front drive engaged and test continued. Completed 50 passes with almost no difficulty. Wheels were not spinning at completion of 50 passes, but vehicle undercarriage was dragging throughout the entire length of test lane
ruck (Modified), Test Weight = 3430 lb														
0.40	0.31	12	17	19	18	19	179.2	50.9	44.1	29.1	69.0	75.8	-- 0.2 0.8	Vehicle operated as 4x2 until immobilized or 10th pass with left-rear wheel in a hole that developed between mounds of grass. Continued test as 4x4 and immobilized on 27th pass with left-front wheel in a hole between grass mounds. Rut depth in hole was 1.2 ft. Cone indexes measured between grass mounds. Cone indexes in grass mounds were 150 to 250 at 2 to 3 in.
0.60	0.46	17	24	31	33	34	179.7	46.0	31.3	27.0	68.7	90.0	-- 0.1 0.5 3.6	Vehicle began having difficulty after 29 passes as holes formed between mounds of grass. Completed 50 passes with considerable difficulty. Cone indexes measured between grass mounds. Rut depths in holes were about 1.3 ft after 5 passes
0.28	0.70	15	20	23	51	96	28.2	21.4	27.6	90.4	102.2	100.6	-- 0.6 1.2 2.6	Test conducted in an area void of vegetation. Vehicle was immobilized on 16th pass but was able to extricate itself. Immobilized again on 19th pass. Vehicle undercarriage was not dragging on either immobilization. Maximum rut depth at point of immobilization was 0.68 ft after 15 passes
0.43	0.68	22	24	26	42	75	32.8	20.8	23.8	83.5	102.6	101.6	-- 0.5 0.8 1.4	Vehicle completed 50 passes with ease. 1-1/2-ton power wagon completed 12 passes in test lane and test vehicle again continued traffic. After 20 passes vehicle was having difficulty and became immobilized when front wheel could not climb over tree root in test lane. Rut depth approximately 0.95 ft at point of immobilization

(Continued)

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Table 2 (Conclu

Test Location	No.	Immobilization: Yes or No	Immobilization: Pass No.	Data Pass No.	Average Cone Index: 0	3	6	9	12	15	18	21	24	30	36	Average Cone Index of Layers: 0-6	3-9	6-12	9-15	12-18	Remolding Index of Layers: 0-6	6-12	12-18
																		1/4-ton M151, 4x4 Truck (Modified), Test					
Fort Lee, Va.	18	No	50	0	83	80	61	70	85	117	154	184+	215+	252+	294+	75	70	72	91	119	0.18	0.46	0.68
				10	77	70	48	45	68	116	173	190+	232+	264+	284+								
				50	43	44	65	102	138	186+	222+	247+	272+	290+	300+								
Fort Lee, Va.	19	Yes	26	0	38	78	70	64	72	124	165	224+	261+	276+	288+	62	71	69	87	120	0.20	0.42	0.74
				10	18	46	48	48	82	116	154	226+	250+	264+	296+								
Fort Lee, Va.	20	Yes	14	0	42	54	44	40	58	90	124	178+	216+	254+	284+	47	46	47	63	91	0.28	0.56	0.61
				14	24	31	38	55	87	150+	188+	238+	279+	284+	294+								
																			1/2-ton M274, 4x4 Carrier (Mule)				
Vicksburg, Miss.	37	Yes	1	0	4	26	45	48	46	47	50	56	62	73	78	25	40	46	47	48	0.78	0.68	0.83
Vicksburg, Miss.	49	No	50	0	17	24	29	32	38	50	54	62	64	66	68	23	28	33	40	47	0.75**	0.76	0.62
				1	24	26	28	32	47	52	54	53	61	71	74								
				10	32	37	38	38	52	56	66	64	70	75	76								
				50	26	34	40	44	56	61	63	67	70	74	78								
Vicksburg, Miss.	50	Yes	1	0	7	12	14	22	36	43	46	52	58	60	63	11	16	24	34	42	0.65	0.63	0.75**
Vicksburg, Miss.	51	Yes	24	0	15	22	26	32	34	36	38	45	52	63	64	21	27	31	34	36	0.64	0.68	0.75**
				1	14	19	26	34	37	36	39	58	50	53	60								
				10	11	21	25	34	34	38	42	51	54	56	62								
				24	8	18	26	34	42	50	56	62	64	66	68								
Vicksburg, Miss.	52	No	50	0	20	28	30	38	40	38	42	46	44	53	66	26	32	36	39	40	0.71	0.72	0.75**
				1	24	30	33	35	40	40	43	45	50	54	60								
				10	23	33	36	38	40	40	45	46	50	54	62								
				50	20	31	39	39	43	46	50	49	56	58	62								
Vicksburg, Miss.	53	Yes	19	0	12	20	27	34	42	44	44	52	54	59	68	20	27	34	40	43	0.75	0.67	0.75**
				1	12	19	26	34	40	40	41	46	49	54	60								
				19	12	22	29	38	40	48	54	62	66	68	68								
Vicksburg, Miss.	86	Yes	3	0	7	10	16	19	45	64	85	106	106	--	--	11	15	27	43	65	0.61	0.58	0.75**
Vicksburg, Miss.	34	No	50	0	8	31	50	48	36	34	38	44	53	66	78	30	43	45	39	36	0.73	0.72	0.69
				50	24	34	34	38	44	55	66	81	85	95	100								
Vicksburg, Miss.	35	Yes	1	0	3	19	35	55	41	38	38	43	45	48	53	19	36	44	45	39	0.66	0.82	0.80
Vicksburg, Miss.	36	No	71	0	7	44	53	49	42	40	50	57	63	69	73	35	49	48	44	44	0.80	0.65	0.68

* Ruts measured after vehicle was retrieved.
** Remolding index estimated from adjacent test areas.

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Table 2 (Concluded)

Remolding Index of Layers 0-6	6-12	12-18	Rating Cone Index of Layers 0-6	3-9	6-12	9-15	12-18	Moisture Content of Layers, % Dry Wt 0-6	6-12	12-18	Dry Density of Layers, pcf 0-6	6-12	12-18	Rut Depth in.	Remarks
(Modified), Test Weight = 3430 lb (Continued)															
	0.46	0.68	14	22	33	52	81	26.9	21.0	23.4	91.2	100.2	99.4	-- 0.6 6.0	Test conducted in an area cleared of woody underbrush but covered with blade grass. Vehicle was having difficulty after 42 passes as holes developed along the test lane. Completed 50 passes with some difficulty as wheels slipped. Maximum rut depth was about 1 ft
	0.42	0.74	12	22	29	50	89	30.4	24.2	24.9	88.0	94.4	101.8	-- 2.2	Test conducted on an area cleared of woody underbrush. Vehicle wheels began to slip on 24th pass and was immobilized on 26th pass. Vehicle had to be towed out of lane
	0.56	0.61	13	12	26	37	56	32.6	25.2	24.6	83.0	91.6	96.4	-- 4.9	Test lane covered with blade grass only. Vehicle wheels began slipping on 13th pass and was immobilized on 14th pass. Undercarriage was dragging at point of immobilization
4 Carrier (Mule), Test Weight = 1260 lb															
	0.68	0.83	20	22	31	36	40	76.0	62.6	47.9	56.0	63.2	71.6	--	Surface same as test 35 (see below). Vehicle immobilized in forward on 1st pass after considerable spinning of wheels without movement. Vehicle was able to extricate itself with the aid of one man pushing. Undercarriage did not drag
**	0.76	0.62	17	21	25	28	29	74.3	59.5	39.6	53.0	63.4	80.4	-- 0.9 2.4 4.6	Vehicle completed 50 passes without difficulty
	0.63	0.75**	7	10	15	26	32	105.8	78.7	64.8	42.8	53.4	61.8	--	Vehicle immobilized on 1st pass, undercarriage dragging, could not extricate itself, extricated by manpower
	0.68	0.75**	13	18	21	26	27	93.2	84.3	65.5	46.6	51.4	61.0	-- 0.7 3.5 7.6	Considerable slip on 15th pass. Vehicle tilted to left through entire test lane, undercarriage dragging. Vehicle seemed to be underpowered, could not spin wheels except in a surge. Immobilized on 24th pass, still could not spin wheels. It is believed that the vehicle could not have completed 50 passes even with adequate power
	0.72	0.75**	18	23	26	29	30	86.5	71.0	78.0	47.6	51.8	54.1	-- 0.4 1.5 3.5	Vehicle completed 50 passes without experiencing serious difficulty; however, vehicle tilted to left side along the entire test lane. Undercarriage did not drag
	0.67	0.75**	15	19	23	30	32	93.7	86.2	83.4	44.9	49.8	51.6	-- 0.6 7.6	Undercarriage of vehicle dragged on 15th pass, considerable slip was experienced on 16th pass. Vehicle immobilized on 19th pass. Vehicle could not spin wheels. It is believed that the vehicle could not have completed 50 passes even with adequate power
	0.58	0.75**	7	2	16	32	49	93.3	85.0	71.7	47.3	49.7	57.0	--	No surface water. Vehicle immobilized on 3d pass, undercarriage dragging. Extricated by manpower
	0.72	0.69	22	31	32	27	25	69.2	59.4	62.9	58.8	64.1	62.4	-- 8.6	Surface 2 or 3 in. of soil was extremely wet, soft, and slippery, causing vehicle to experience difficulty on 1st pass when high slippage occurred. Vehicle had to back up and obtain momentum to complete 1st pass. Vehicle completed 50 passes with no other difficulty
	0.82	0.80	13	27	36	36	31	71.4	60.0	55.4	56.9	65.0	68.6	5.0*	Surface 2 or 3 in. of soil was extremely wet, soft, and slippery. Vehicle was immobilized going forward on 1st pass, but was able to extricate itself in reverse. No other traffic was attempted, undercarriage did not drag
	0.65	0.68	28	35	31	29	30	64.6	63.0	55.4	61.7	63.2	68.2	--	Surface conditions were about the same as those for test 35 but not as critical. Vehicle completed 71 passes without experiencing serious difficulty

B

Table 3

Vehicle Data from Other Test Programs

Vehicle			Wheel and Tire Description										
Description	Weight, lb Empty	Weight, lb Test	Nominal Width in.	Rim Diam in.	Wheel Diam in.	No. of Tires	Inflation Pressure psi	Total Contact Area, sq in.*	Avg Contact Pressure, psi	Ply Rating	Ground Clearance in.	Brake Horsepower	Transmission
LeTourneau electric digger, model L-28	72,000	85,000	33	35	75**	4	75	1473	57.7	36	13	420	Hydraulic
LeTourneau log stacker, model F	--	73,000	33	35	75**	4	40	1650	44.2	36	20	290	Hydraulic
6-ton cargo truck, 6x6	22,070	34,800	14	20	48+	6	15	996	35.0	20	13	202	Mechanical
4-ton cargo truck, 6x6	18,050	21,100	14	20	48+	6	15	930	27.0	12	15	112	Mechanical
2-1/2-ton cargo truck, 6x6	10,350	16,300	10.5	18	39+	6	60	294	55.5	10	15	92	Mechanical
5-ton XM520 GOER, 4x4 (15.00-34 tires)	15,830	26,700	15	34	64+	4	18	1340	19.9	10	22	93	Hydraulic
5-ton XM520 GOER, 4x4 (18.00-26 tires)	15,830	26,700	18	26	62+	4	18	1550	17.2	10	21	93	Hydraulic
2-ton Meili Flex-Trac, 4x4	9,100	9,100	10	20	40+	4	--	--	--	12	11	95	Mechanical
2-ton Meili Flex-Trac, 6x6	9,100	9,100	10	20	40+	6	--	--	--	12	11	95	Mechanical
Gama goat, 6x6	3,640	5,650	12.4	16	40.8+	6	--	--	--	6	15	65	Mechanical

Note: See text (paragraph 43) for data source.
* From hard-surface prints.
** Measured.
\+ Computed (rim diameter plus twice tire width).

Table 4

Data Pertinent to the Development of Revised Mobility Index Formula

No.	Vehicle Nomenclature	Experimental VCI	Computed VCI Original Formula	Computed VCI Revised Formula	Unit Error Original Formula	Unit Error Revised Formula	Percent Error* Original Formula	Percent Error* Revised Formula
1	LeTourneau electric digger, model L-28	185	53	192	-132	+7	71.4	3.8
2	LeTourneau log stacker, model F	150	50	142	-100	-8	66.7	5.3
3	6-ton cargo truck, 6x6	75	69	74	-6	-1	8.0	1.3
4	2-1/2-ton cargo truck, 6x6	70	66	63	-4	-7	5.7	10.0
5	4-ton cargo truck, 6x6	65	60	58	-5	-7	7.7	10.8
6	5-ton XM520 GOER, 4x4, 15.00-34 tires	63	56	65	-7	+2	11.1	3.2
7	16-ton XM438E2 GOER, 4x4, without chains	62	47	53	-15	-9	24.2	14.5
8	16-ton XM438E2 GOER, 4x4, with chains	60	46	52	-14	-8	25.0	13.3
9	Tournadozer tractor, 4x4	60	52	58	-8	-2	13.3	3.3
10	3/4-ton M37 truck, 4x4, loaded	58	64	59	+6	+1	10.3	1.7
11	5-ton XM520 GOER, 4x4, 18.00-26 tires	57	54	57	-3	0	5.3	0.0
12	2-ton Meili Flex-Trac, 4x4, with chains	52	57	55	+5	+3	9.6	5.8
13	Bucket loader, 4x4	50	49	49	-1	-1	2.0	2.0
14	3/4-ton M37 truck, 4x4, empty	50	58	52	+8	+2	16.0	4.0
15	Willys station wagon, 4x4	50	60	50	+10	0	20.0	0.0
16	1-1/2-ton power wagon (modified)	42	44	37	+2	-5	4.8	11.9
17	2-ton Meili Flex-Trac, 6x6, with chains	40	49	44	+9	+4	22.5	10.0
18	Gama goat, 6x6	37	42	33	+5	-4	13.5	10.8
19	1/4-ton M151 truck (modified)	23	37	23	+14	0	60.9	0.0
20	1/2-ton M274 carrier	20	46	22	+26	+2	130.0	10.0
		Absolute average all vehicles			19.0	3.6	26.4	6.1
		Algebraic average all vehicles			-10.5	-1.6	--	--
		Absolute average without vehicles 1 and 2			8.2	3.2	21.7	6.3
		Algebraic average without vehicles 1 and 2			+1.2	-1.7	--	--

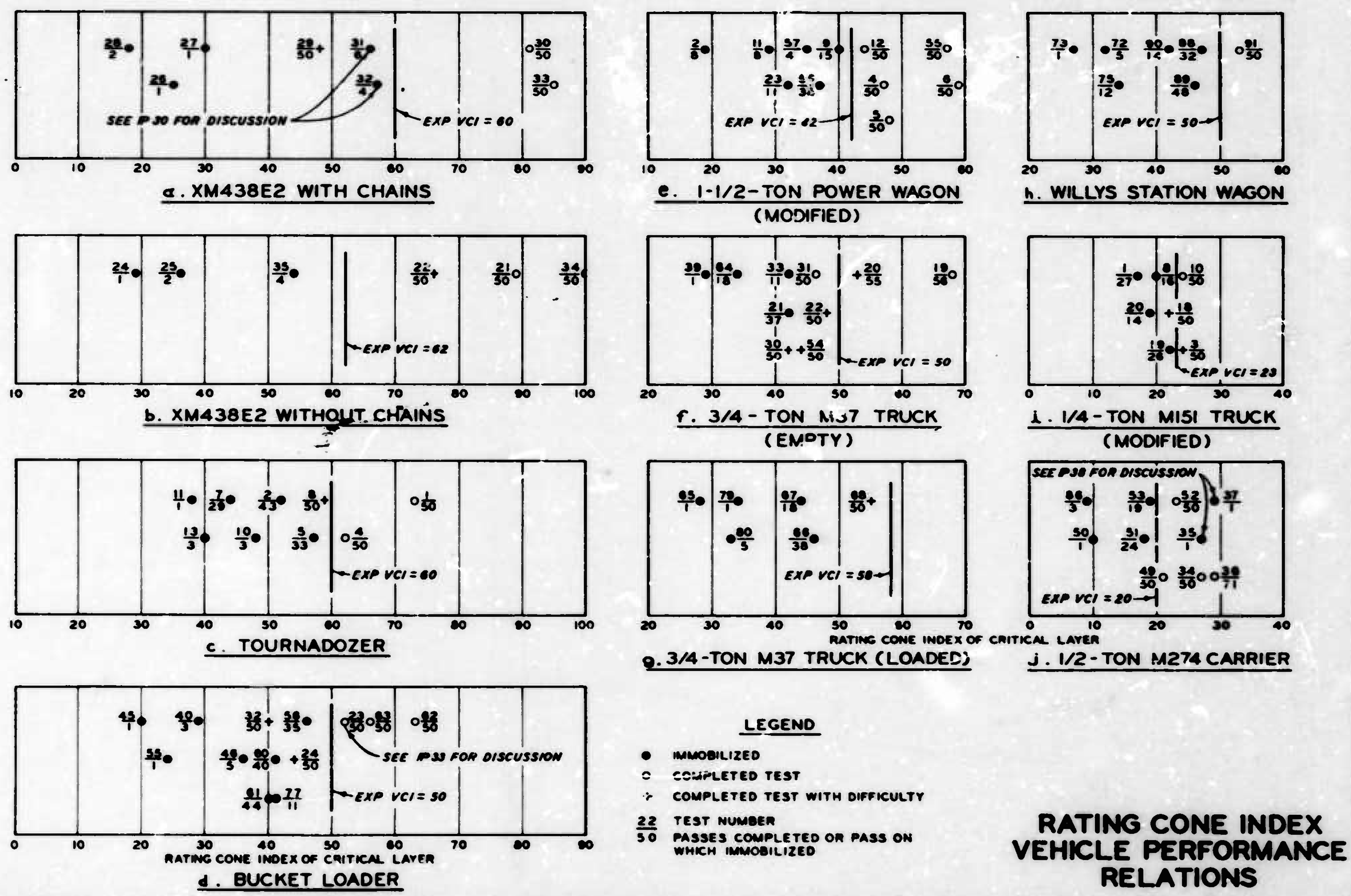
* Percent error = $\frac{\text{unit error}}{\text{exp VCI}} \times 100.$

Table 5

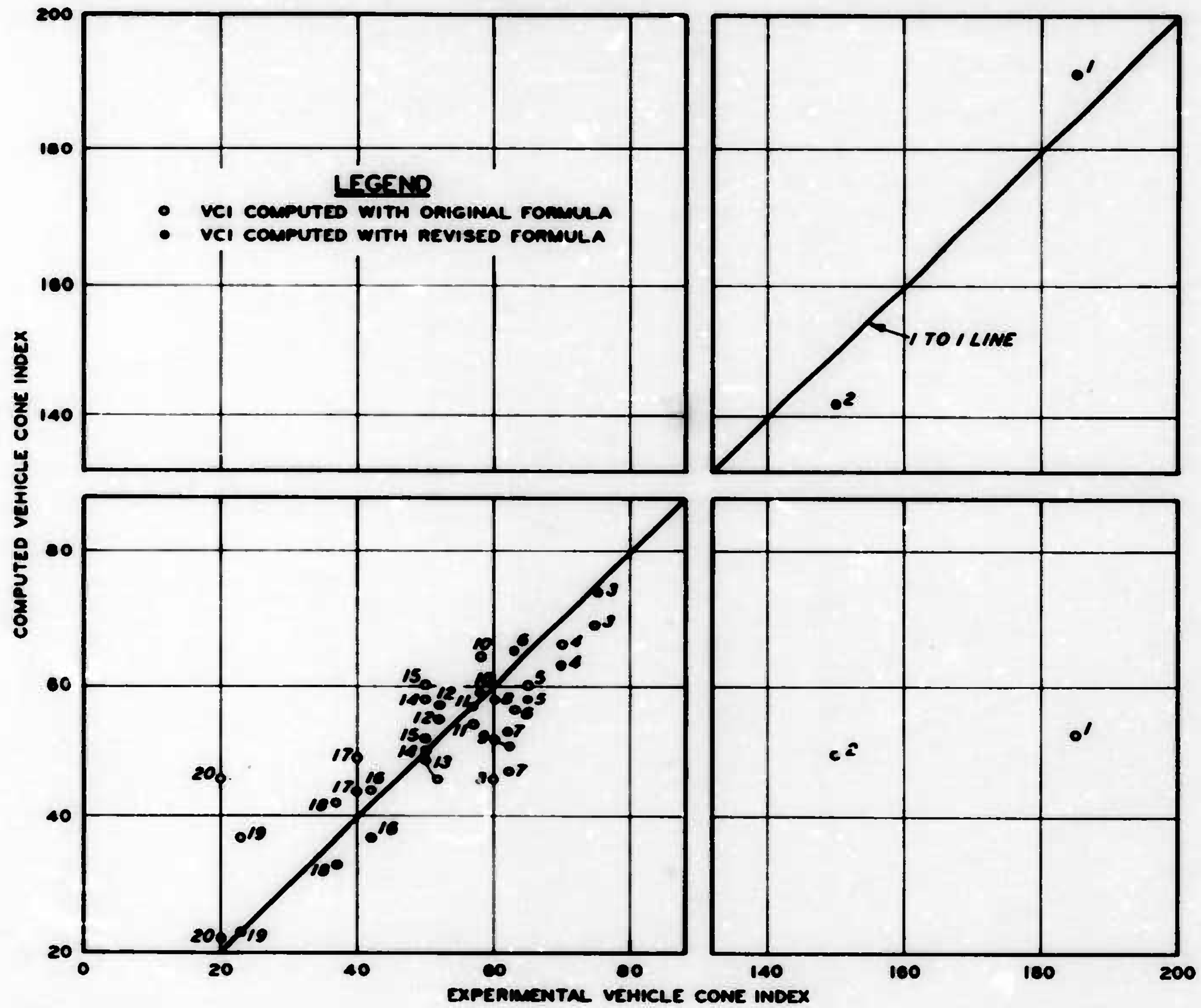
Summary of Vehicle and Test Data Pertinent to Validity Check of Revised MI Formula

Vehicle	Vehicle Data: Test Weight lb	Tire Data: Nominal Width in.	Tire Data: Rim Diam in.	Tire Data: Wheel Diam in.	Tire Data: No. of Tires	Ground Clearance in.	Brake Horsepower	Transmission Type	Computed Vehicle Cone Index	Test Data: Data Source Test No.	Immobilization: Yes or No	Immobilization: Pass No.	Rating Cone Index of Critical Layer	Item No. (This Report)
Data from TM 3-240, 12th Supplement[11]														
1/4-ton M38 truck, 4x4	3,500	7	16	30	4	9	51	Mechanical	48	38	Yes	20	31	1
2-1/2-ton M135 truck, 6x6	17,700	11	20	42	6	12.5	130	Hydraulic	61	39	Yes	6	32	2
										40	Yes	17	48	3
										41	Yes	10	46	4
										42	No	50	87	5
										43	No	50	113	6
										44	No	58	132	7
2-1/2-ton M34 truck, 6x6	17,500	11	20	42	6	12.5	127	Mechanical	61	45	Yes	7	34	8
										46	Yes	41	57	9
										47	No	50	275	10
5-ton M41 truck, 6x6	29,800	14	20	48	6	13	196	Mechanical	67	50	No	60	92	11
5-ton M62 wrecker, 6x6	33,300	11	20	42	10	10	224	Mechanical	74	62	No	50	86	12
Data from TM 3-240, 13th Supplement[12]														
3/4-ton M37 truck, 4x4	7,400	9	16	34	4	11	78	Mechanical	61	28	Yes	1	40	13
										29	Yes	8	46	14
										30	No	67	53	15
										31	No	50	83	16
2-1/2-ton CCKW353 truck, 6x6	16,600	7.5	20	35	10	10	91	Mechanical	70	38	Yes	38	48	17
										39	Yes	5	42	18
										40	No	50	85	19
										41	No	50	141	20
										42	No	50	174	21
2-1/2-ton M47 truck, 6x6	13,500	11	20	42	6	14	127	Mechanical	52	8	Yes	11	20	22
										9	Yes	35	21	23
										10	Yes	15	28	24
										11	Yes	3	33	25
										12	No	40	69	26
2-1/2-ton M47 truck, 6x6	18,500	11	20	42	6	14	127	Mechanical	64	13	Yes	4	15	27
										14	Yes	7	22	28
										15	Yes	19	148	29
										16	No	60	91	30
										17	No	40	214	31
										18	Yes	16	19	32
										19	Yes	3	22	33
										20	Yes	3	34	34
										21	Yes	5	23	35
										22	Yes	2	31	36
										23	Yes	4	33	37
										24	Yes	4	38	38
										25	Yes	11	50	39
										26	No	50	62	40
5-ton M41 truck, 6x6	29,800	14	20	48	6	13	196	Mechanical	67	32	Yes	12	19	41
										33	Yes	--	20	42
										34	Yes	4	58	43
										35	Yes	16	71	44
										36	No	50	137	45
										37	No	50	104	46
Data from MP 4-505[13]														
2-1/2-ton M34 truck, 6x6	17,190	11	20	42	6	10	127	Mechanical	61	4	No	50	118	47
2-1/2-ton M34 (modified No. 1) truck, 6x6	17,190	14.75	20	49.5	6	13	127	Mechanical	45	15	No	50	57	48
2-1/2-ton M34 (modified No. 2) truck, 6x6	17,190	18*	22.5	45	6	13	127	Mechanical	41	16	Yes	33	46	49
2-1/2-ton M35 truck, 6x6	18,230	9	20	38	10	11	127	Mechanical	59	17	No	50	61	50
2-1/2-ton M35 (modified) truck, 6x6	18,230	12.50	20	45	6	14	127	Mechanical	53	18	Yes	4	46	51
2-1/2-ton XM410 truck, 8x8	14,706	16	20	52	8	15	154	Hydraulic	37	19	No	10	65	52
5-ton M54 truck, 6x6	30,295	11	20	42	10	12	196	Mechanical	68	7	No	50	75	53
5-ton M41 (modified) truck, 6x6	29,838	23*	23.5	52	6	14	196	Mechanical	44	8	No	50	66	54
5-ton Scamp, 4x4	21,400	14	24	52	4	16	75	Mechanical	70	9	Yes	6	36	55
5-ton XM453E2 truck, 8x8	22,975	16	20	52	8	15	175	Mechanical	46	10	Yes	7	58	56
5-ton XM520 GOER, 4x4	26,230	15	34	64	4	21	110	Hydraulic	67	12	Yes	2	44	57
8-ton XM520E1 GOER, 4x4	42,800	18	33	69	4	24	213	Hydraulic	112	1	No	50	87	58
8-ton XM409E6 truck, 8x8	45,250	16	20	52	8	14	242	Hydraulic	62	2	No	50	75	59
16-ton XM437E1 GOER, 4x4	71,070	29.5	25	74	4	30	280(est)	Hydraulic	171	3	Yes	2	110	60
Data from MP 4-556[14]														
3/4-ton XM408 truck, 6x6	4,962	10*	16.5	30	6	9	61	Mechanical	37	A1	No	50	79	61
1-1/2-ton FC170 truck, 4x4	7,900	9	16	34	4	11	85	Mechanical	64	A4	No	50	76	62
8-ton XM520E1 GOER, 4x4	43,000	18	33	69	4	24	176	Hydraulic	112	A2	Yes	38	90	63
16-ton XM438E2 GOER, 4x4	72,800	29.5	25	74	4	30	285	Mechanical	155	A5	Yes	13	81	64

* Wide-base tire.

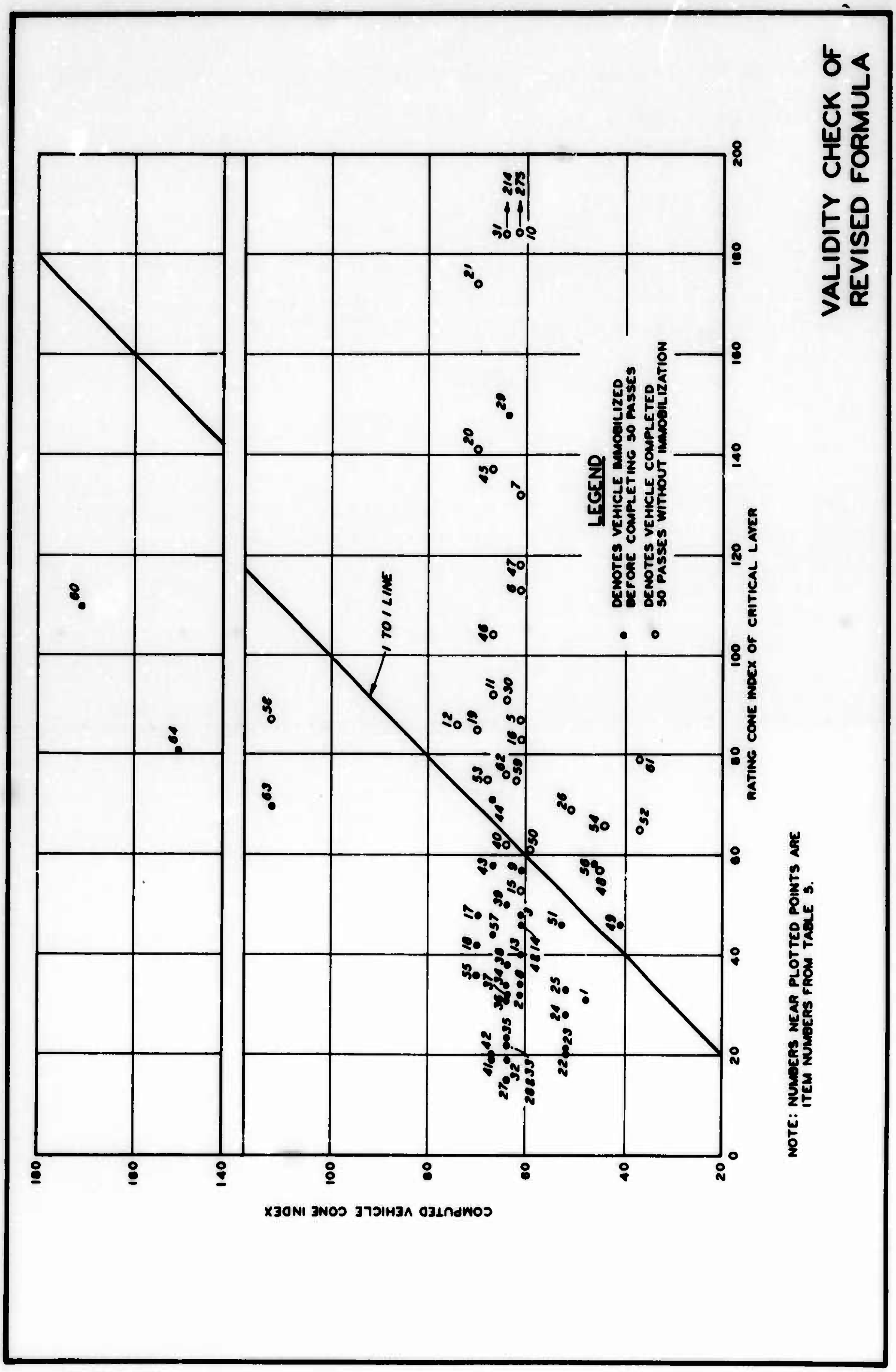


RATING CONE INDEX
VEHICLE PERFORMANCE
RELATIONS



NOTE: NUMBERS DESIGNATE VEHICLE NUMBERS FROM TABLE 4.

COMPARISONS OF EXPERIMENTAL AND COMPUTED VEHICLE CONE INDEXES



VALIDITY CHECK OF REVISED FORMULA

APPENDIX A: VEHICLE CONE INDEX COMPUTATIONS

1. The vehicle cone index (VCI) is the minimum rating cone index (RCI) that will permit a vehicle to complete 50 passes in fine-grained soils. It is determined by first computing a mobility index (MI) from an empirical formula and then referring to a curve relating MI to VCI.

2. This appendix presents the original mobility index formula for self-propelled wheeled vehicles, the revised mobility index formula for self-propelled wheeled vehicles developed in the main text of this report, and comparisons of VCI's computed using both formulas for a selection of standard military and experimental military vehicles.

Mobility Index (MI)

3. The MI is an abstract number obtained by applying certain vehicle characteristics in the MI formula.

Original MI formula

$$\mathrm{MI} = 0.6\left[\left(\frac{\begin{matrix}\text{contact}\\ \text{pressure}\\ \text{factor}\end{matrix} \times \begin{matrix}\text{weight}\\ \text{factor}\end{matrix}}{\begin{matrix}\text{tire}\\ \text{factor}\end{matrix} \times \begin{matrix}\text{grouser}\\ \text{factor}\end{matrix}} + \begin{matrix}\text{wheel}\\ \text{load}\\ \text{factor}\end{matrix} - \begin{matrix}\text{clear-}\\ \text{ance}\\ \text{factor}\end{matrix}\right) \times \begin{matrix}\text{engine}\\ \text{factor}\end{matrix} \times \begin{matrix}\text{trans-}\\ \text{mission}\\ \text{factor}\end{matrix}\right] + 20$$

Factor No.

$$\text{Contact pressure factor} = \frac{\text{gross weight, lb}}{\text{tire width} \times \text{rim diam} \times \text{No. of tires}} \qquad (1)$$

$$\text{Weight factor} = \begin{cases} >35{,}000 \text{ lb} = 1.10 \\ 15{,}000\text{-}35{,}000 \text{ lb} = 1.00 \\ <15{,}000 \text{ lb} = 0.90 \end{cases} \qquad (2)$$

$$\text{Tire factor} = \frac{1.25 \times \text{tire width, in.}}{100} \qquad (3)$$

		Factor No.
Grouser factor:	With chains = 1.05 Without chains = 1.00	(4)
Wheel load factor	$= \dfrac{\text{gross weight, kips}}{\text{No. of wheels (duals count as one)}}$	(5)
Clearance factor	$= \dfrac{\text{clearance, in.}}{10}$	(6)
Engine factor:	>10 hp/ton = 1.0 <10 hp/ton = 1.1	(7)
Transmission factor:	Hydraulic = 1.00 Mechanical = 1.05	(8)

$$MI = 0.60 \left\{ \left[\frac{(1) \times (2)}{(3) \times (4)} + (5) - (6) \right] \times (7) \times (8) \right\} + 20$$

Revised MI formula

$$MI = \left[\frac{\text{contact pressure factor} \times \text{weight factor}}{\text{tire factor} \times \text{grouser factor}} + \text{wheel load factor} - \text{clearance factor} \right] \times \text{engine factor} \times \text{transmission factor}$$

$$\text{Contact pressure factor} = \frac{\text{gross weight, lb}}{\text{tire width, in.} \times \dfrac{\text{outside diam of tire, in.}}{2} \times \text{No. of tires}} \qquad (1)$$

Weight factor: (2)

Weight Range, lb $\left(\dfrac{\text{Gross Vehicle Wt, lb}}{\text{No. of axles}}\right)$	Weight Factor Equations
<2000	Y = 0.553X
2,000 to 13,500 lb	Y = 0.033X + 1.050
13,501 to 20,000 lb	Y = 0.142X - 0.420
>20,000 lb	Y = 0.278X - 3.115

		Factor No.
where		
	$X = \frac{\text{gross vehicle wt(kips)}}{\text{No. of axles}}$ Y = weight factor	
Tire factor	$= \frac{10 + \text{tire width, in.}}{100}$	(3)
Grouser factor:	With chains = 1.05 Without chains = 1.00	(4)
Wheel load factor	$= \frac{\text{gross weight, kips}}{\text{No. of wheels (duals count as one)}}$	(5)
Clearance factor	$= \frac{\text{clearance, in.}}{10}$	(6)
Engine factor:	>10 hp/ton = 1.00 <10 hp/ton = 1.05	(7)
Transmission factor:	Hydraulic = 1.00 Mechanical = 1.05	(8)

$$MI = \left[\frac{(1) \times (2)}{(3) \times (4)} + (5) - (6)\right] \times (7) \times (8)$$

Vehicle Cone Index (VCI)

4. The VCI of a vehicle can be obtained from a curve of MI versus VCI (plate A1) or more accurately from a tabulation of MI versus VCI, as shown in table A1.

Comparisons of Computed VCI's for Standard and Experimental Military Vehicles

5. Since VCI's computed with the original MI formula have been used for several years and are listed in earlier supplements of the "Trafficability of Soils" series of reports, numerous Miscellaneous Papers, and Department of the Army Technical Bulletin ENG 37, it was felt that a comparison of original and revised VCI computations should be made to show the

range of VCI similarities and areas of VCI divergence with the two formulas.

Standard military vehicles

6. The latest available data source, Department of the Army Technical Manual 9-500,[15]* was used to select representative vehicles for comparisons of VCI's. The vehicles selected are shown in table A2. The characteristics of these vehicles, generally, have changed little since the development of the original MI formula. Table A2 shows that both the original and revised formulas produce VCI's that are in close agreement through the 3/4- and 2-1/2-ton truck range, but the VCI's diverge for the 1/4-, 1/2-, 5-, and 10-ton truck range.

Experimental military vehicles

7. Computed VCI's for selected experimental military vehicles are listed in table A3. Data sources for each vehicle also are shown. The VCI's computed with the revised formula generally are lower than VCI's computed with the original formula for vehicles through the 5-ton rated pay-load range. The revised-formula VCI's are considerably higher than the original-formula VCI's for the 8- and 16-ton vehicles.

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* See Literature Cited at end of main text of this report.

Table A1

Mobility Index Versus Vehicle Cone Index

MI	VCI	MI	VCI	MI	VCI	MI	VCI	MI	VCI
0	3.0	31	39.2	67	55.6	103	72.0	139	88.3
0.25	5.5	32	39.7	68	56.1	104	72.4	140	88.8
0.50	7.0	33	40.1	69	56.5	105	72.9	141	89.2
0.75	8.3	34	40.6	70	57.0	106	73.3	142	89.7
1.00	9.0	35	41.0	71	57.4	107	73.8	143	90.1
1.50	10.8	36	41.5	72	57.9	108	74.2	144	90.6
2.00	12.5	37	42.0	73	58.3	109	74.7	145	91.0
2.50	13.8	38	42.4	74	58.8	110	75.1	146	91.5
3	15.1	39	42.9	75	59.2	111	75.6	147	91.9
4	17.5	40	43.4	76	59.7	112	76.0	148	92.4
5	19.7	41	43.8	77	60.2	113	76.5	149	92.8
6	21.5	42	44.3	78	60.6	114	77.0	150	93.3
7	23.0	43	44.7	79	61.1	115	77.4	151	93.8
8	24.2	44	45.2	80	61.5	116	77.9	152	94.2
9	25.3	45	45.6	81	62.0	117	78.3	153	94.7
10	26.4	46	46.1	82	62.4	118	78.8	154	95.1
11	27.3	47	46.5	83	62.9	119	79.2	155	95.6
12	28.1	48	47.0	84	63.3	120	79.7	156	96.0
13	28.9	49	47.4	85	63.8	121	80.1	157	96.5
14	29.6	50	47.9	86	64.2	122	80.6	158	96.9
15	30.4	51	48.4	87	64.7	123	81.0	159	97.4
16	31.0	52	48.8	88	65.2	124	81.5	160	97.8
17	31.7	53	49.3	89	65.6	125	82.0	161	98.3
18	32.3	54	49.7	90	66.1	126	82.4	162	98.7
19	32.9	55	50.2	91	66.5	127	82.8	163	99.2
20	33.5	56	50.6	92	67.0	128	83.3	164	99.6
21	34.1	57	51.1	93	67.4	129	83.8	165	100.1
22	34.6	58	51.5	94	67.9	130	84.2	166	100.6
23	35.2	59	52.0	95	68.3	131	84.7	167	101.0
24	35.8	60	52.4	96	68.8	132	85.1	168	101.5
25	36.3	61	52.9	97	69.2	133	85.6	169	101.9
26	36.8	62	53.3	98	69.7	134	86.0	170	102.4
27	37.3	63	53.8	99	70.1	135	86.5	171	102.8
28	37.8	64	54.2	100	70.6	136	86.9	172	103.3
29	38.3	65	54.7	101	71.1	137	87.4	173	103.7
30	38.7	66	55.2	102	71.5	138	87.8	174	104.2

Note: For MI above approximately 40, VCI obtained from equation
$VCI = 25.2 + (0.454 \times MI)$.

Table A2

Vehicle Cone Index Requirements for Representative

Standard Military Self-Propelled Wheeled Vehicles

Rated Off-Road Pay Load, lb	Identification		Gross Weight lb	Tire Data				Vehicle Cone Index	
	No.	Nomenclature		Size	Normal Inflation Pressure, psi	Ply Rating	No.	Original Formula	Revised Formula
1/4-ton	M38	Truck, utility, 4x4	3,550	7.00-16	25	6	4	57	48
	M38A1, M38A1C	Truck, utility, 4x4	3,490	7.00-16	22	6	4	57	47
	M151	Truck, utility, 4x4	2,940	7.00-16	15	6	4	53	41
	M422	Truck, utility, 4x4	2,550	6.00-16	20	6	4	57	41
1/2-ton	M274	Carrier, light weapons, 4x4	1,970	7.50-10	7.5	4	4	53	31
3/4-ton	M37, M37B1	Truck, cargo, 4x4	7,417	9.00-16	40	8	4	64	61
	M201, M201B	Truck, maintenance, 4x4	8,800	9.00-16	40	8	4	70	66
2-1/2-ton	M135	Truck, cargo, 6x6	18,090	11.00-20	35	12	6	61	61
	M34	Truck, cargo, 6x6	17,190	11.00-20	50	12	6	60	61
	M35	Truck, cargo, 6x6	17,880	9.00-20	45	8	10	61	59
	M36, M36C	Truck, cargo, 6x6	18,915	9.00-20	45	8	10	63	61
	M211	Truck, cargo, 6x6	18,930	9.00-20	15	8	10	60	59
	M59	Truck, dump, 6x6	17,598	9.00-20	45	8	10	60	58
	M215	Truck, dump, 6x6	18,620	9.00-20	45	8	10	60	59
	M49, M49C	Truck, tank, 6x6	18,490	9.00-20	45	8	10	61	60
	M217, M217C	Truck, tank, 6x6	20,105	9.00-20	45	8	10	62	62
	M50	Truck, tank, 6x6	18,888	9.00-20	45	8	10	62	61
	M222	Truck, tank, 6x6	17,950	9.00-20	45	8	10	60	57
	M109	Truck, van, 6x6	20,581	9.00-20	45	8	10	64	65
	M220	Truck, van, 6x6	20,435	9.00-20	45	8	10	62	62
	M108	Truck, wrecker, 6x6	19,785	9.00-20	45	8	10	63	63
	M60	Truck, wrecker, 6x6	24,460	9.00-20	45	8	10	70	74
5-ton	M41	Truck, cargo, 6x6	29,835	14.00-20	45	12	6	64	67
	M54	Truck, cargo, 6x6	29,580	11.00-20	70	12	10	62	67
	M55	Truck, cargo, 6x6	34,414	11.00-20	70	12	10	69	76
	M51	Truck, dump, 6x6	32,664	11.00-20	70	12	10	68	72
	M62	Truck, wrecker, 6x6	41,025	11.00-20	70	12	10	81	89
	M543	Truck, wrecker, 6x6	41,790	11.00-20	70	12	10	83	92
10-ton	M125	Truck, cargo, 6x6	51,000	14.00-24	90	20	10	62	84

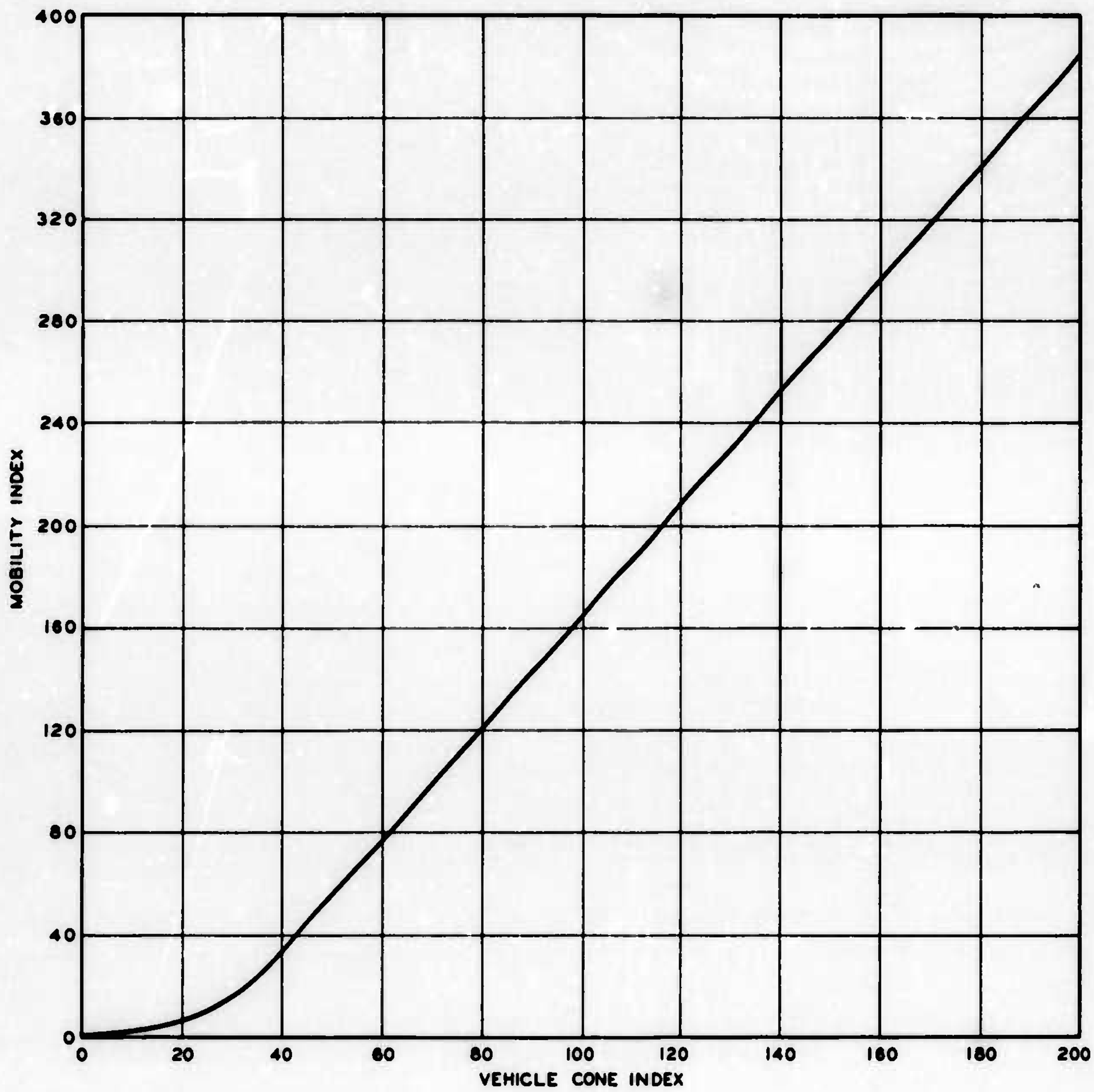
Note: Data source, DA TM 9-500[15] or DA TM 9-236[16] (see Literature Cited at end of main text).

Table A3

Vehicle Cone Index Requirements for Representative Experimental Military and Modified Standard Military Self-Propelled Wheeled Vehicles

Rated Off-Road Pay Load, lb	Indentification No.	Indentification Nomenclature	Gross Weight lb	Tire Data Size	Tire Data Normal Inflation Pressure, psi	Tire Data Ply Rating	Tire Data No.	Vehicle Cone Index Original Formula	Vehicle Cone Index Revised Formula	Data Source*
1/4-ton	M151 Mod	Truck, utility, 4x4	3,560	9.00-14**	20 to 30	2	4	51	40	WES Contract Report 3-152, July 1966[17]
	M151 Mod	Truck, utility, 4x4	3,560	36x20-14R	3	4	4	38	24	WES Contract Report 3-152, July 1966[17]
1/2-ton	M274 Mod	Carrier, light weapons, 4x4	1,970	16x15-6R	3	2	4	41	25	WES Contract Report 3-152, July 1966[17]
	M274 Mod	Carrier, light weapons, 4x4	1,970	24x12-10R	2	2	4	41	24	ATAC Report RAVE I, 29 Oct 1962[18]
3/4-ton	M37 Mod	Truck, cargo, 4x4	7,240	46x18-16R	3	4	4	42	34	WES Contract Report 3-152, July 1966[17]
	M37 Mod	Truck, cargo, 4x4	7,240	14-18†	7 to 11	--	4	45	36	USA Trans Board Wheeltrack I, 1963[1]
	XM408	Truck, cargo, 6x6	4,960	10-16.5†	6	--	6	45	37	USA Trans Board Wheeltrack I, 1963[1]
1-1/4-ton	XM561	Truck, cargo, 6x6	9,555	11.00-18††	12	4	6	49	44	MRDC Thailand Report 65-025, Oct 1965[19]
	XM561 Mod	Truck, cargo, 6x6	10,006	36x20-14R	6	4	6	41	33	MRDC Thailand Report 65-025, Oct 1965[19]
2-1/2-ton	M34 Mod	Truck, cargo, 6x6	18,057	14.75-20	8	12	6	51	45	USA Trans Board Wheeltrack I, 1963[1]
	M34 Mod	Truck, cargo, 6x6	17,686	18-22.5†	15	--	6	44	41	USA Trans Board Wheeltrack I, 1963[1]
	XM410	Truck, cargo, 8x8	15,050	16-20†	5	10	8	43	37	USA Trans Board Wheeltrack I, 1963[1]
5-ton	M41 Mod	Truck, cargo, 6x6	30,660	23-23.5†	14	--	6	45	44	USA Trans Board Wheeltrack I, 1963[1]
	XM453E2	Truck, cargo, 8x8	22,975	16-20††	11	10	8	48	46	USA Trans Board Wheeltrack I, 1963[1]
	XM453E3	Truck, cargo, 8x8	23,568	18-22.5†	14	--	8	44	41	USA Trans Board Wheeltrack I, 1963[1]
	XM656	Truck, cargo, 8x8	26,000	16.00-20	--	12	8	49	42	Aberdeen Proving Ground Characteristic Sheet (Tentative 28 Aug 1964)
8-ton	XM520E1	Truck, cargo, 4x4	43,410	18.00-33	19	10	4	62	112	USA Trans Board Wheeltrack I, 1963[1]
	XM409E8	Truck, cargo, 8x8	46,450	16.00-20	16	10	8	64	62	USA Trans Board Wheeltrack I, 1963[1]
16-ton	XM437E1	GOER, cargo, 4x4	71,500	29.5-25	22	16	4	59	171	USA Trans Board Wheeltrack I, 1963[1]

* See Literature Cited at end of the main text.
** Buffed smooth.
† Wide-base tire.
†† Special soft tire.



NOTE: FOR MI ABOVE APPROXIMATELY 40, VCI CAN BE OBTAINED FROM THE EQUATION VCI = 25.2 + (0.454 X MI).

MOBILITY INDEX VS
VEHICLE CONE INDEX

APPENDIX B: STATISTICAL EVALUATION OF ORIGINAL AND REVISED MOBILITY INDEX FORMULAS

1. The development of the revised MI formula shown in Appendix A and discussed in the main text of the report was accomplished by trial-and-error adjustment of constants and the ingredients of the eight factors of the original formula. This approach was intentional, since it was desired to have any revised formula be similar in form, i.e. retain the same factors of the original formula. That the approach was successful can be seen by comparing the two formulas and comparing differences between the experimental VCI's and computed VCI's (table 4, main text). As a further check it was decided to perform a more complicated analysis (with the aid of an electronic digital computer) that would statistically relate the experimental MI's (converted from experimental VCI's, table A1) to the combinations of vehicle factors contained in the formulas. This analysis was performed by a multiple linear regression method as described herein.

2. Data used in the analysis were from tables B1 and B2; MI factors used were those from the MI formulas in Appendix A.

Analysis Technique

3. The multiple regression technique was used to determine the association between the dependent variable (MI) and the independent variables (combinations of vehicle factors). Statistical techniques were also used to measure the quality of the association between the dependent and independent variables. Plate 2 (main text) shows that a linear relation exists between computed and experimental VCI's; therefore, this evaluation was made using a multiple linear regression method. The actual computations were made by an electronic digital computer programmed for a multiple linear regression.[6] This program requires the computation of regression coefficients that will provide the best fit of an equation to a set of observations in the form:

$$Y = b_0 + b_1X_1 + b_2X_2 + \ldots b_nX_n$$

where

Y	is the dependent variable (the MI corresponding to the experimental VCI)
b_0 , b_1 , $b_2 \ldots b_n$	are the coefficients to be determined
X_1 , $X_2 \ldots X_n$	independent variables (vehicle factors)

The regression also provides statistical quantities giving a measure of the reliability of the regression equation.

4. In order to evaluate statistically the original and revised mobility index formulas (Appendix A, paragraph 3) in as close to their original form as possible, it was decided that a four-variable (one dependent and three independent) multiple linear regression would best serve the purpose. This was accomplished by using the MI corresponding to the experimental VCI of the 20 vehicles listed in table 4 of the main text as the dependent variable (Y) and grouping the eight vehicle factors of the original and revised MI formulas (including the two constants of the original formula) into three independent variables (X_1 , X_2 , and X_3) for each of the two formulas (original and revised). The three independent variables (X_1 , X_2 , and X_3) for each of the 20 vehicles for the original and revised mobility index formulas were obtained as follows:

<u>Independent variables from original MI formula:*</u>

$$X_1 = 0.60 \left[\frac{(1) \times (2)}{(3) \times (4)} \times (7) \times (8) \right] + 10$$

$$X_2 = 0.60 \left[(5) \times (7) \times (8) \right] + 10$$

$$X_3 = 0.60 \left[(6) \times (7) \times (8) \right]$$

<u>Independent variables obtained from revised MI formulas:*</u>

$$X_1 = \left[\frac{(1) \times (2)}{(3) \times (4)} \right] \times (7) \times (8)$$

---

* Numbers in parentheses have same significance as in Appendix A.

$$X_2 = (5) \times (7) \times (8)$$

$$X_3 = (6) \times (7) \times (8)$$

The computed values for the three independent variables (X_1, X_2, and X_3) for the 20 vehicles used in this analysis are included in tables B1 and B2 for the original and revised formulas, respectively. Note that the same computed VCI obtained from the original and revised formulas (presented in table 4, main text) can be obtained for each of the 20 vehicles by substituting values of X_1, X_2, and X_3 from tables B1 and B2 into the equation below and converting mobility index to VCI from table A1.

$$\text{Mobility index} = X_1 + X_2 - X_3$$

For example, from table B2, vehicle 1 (LeTourneau electric digger, model L-28), the values of X_1, X_2, and X_3 (independent variables) obtained from the revised formula as discussed above are

$$X_1 = 348.0$$

$$X_2 = 21.2$$

$$X_3 = 1.3$$

and substituting the values for X_1, X_2, and X_3 in the above formula the computed MI is:

$$MI = 348.0 + 21.2 - 1.3 = 367.9$$

Converting the above-computed MI (367.9) to VCI is accomplished by the equation (from table A1):

$$VCI = 25.2 + (0.454 \times 367.9) = 192.22$$

The above-computed VCI rounded to the nearest whole number (192) is the same as that computed for vehicle 1 (LeTourneau electric digger) by the revised formula as shown in table 4 of the main text.

5. The computed values for the three independent variables (X_1 , X_2 , and X_3 --combinations of vehicle factors) and the dependent variable (Y = MI corresponding to the measured VCI) for each of the 20 vehicles listed in tables B1 and B2 for the original and revised MI formulas, respectively, were supplied to the electronic digital computer. Separate computations were made for each formula. Results of these computations are presented in the following paragraphs.

Results of Multiple Linear Regression Computations

MI formulas

6. The multiple linear regression equation for predicting mobility index from the experimental mobility index and the eight factors (combined into three independent factors) of the original mobility index formula for the 20 vehicles used in these computations is

$$\hat{MI} = 0.65X_1 + 26.34X_2 - 102.84X_3 - 201.80$$

When the original factor numbers are substituted for X_1 , X_2 , and X_3 (see paragraph 4), the equation above becomes

$$\hat{MI} = 0.65\left\{0.60\left[\frac{(1) \times (2)}{(3) \times (4)} \times (7) \times (8)\right] + 10\right\} + 26.34\left\{0.60\left[(5) \times (7) \times (8)\right] + 10\right\} - 102.84\left\{0.60\left[(6) \times (7) \times (8)\right]\right\} - 201.80$$

The equation above can be simplified as follows:

$$\hat{MI} = 0.60 \times (7) \times (8)\left\{0.65\left[\frac{(1) \times (2)}{(3) \times (4)}\right] + 26.34 \times (5) = 102.84 \times (6)\right\} + 68.10$$

7. The multiple linear regression equation for predicting mobility index from the experimental mobility index and the eight factors (combined into three independent factors) of the revised mobility index formula for the 20 vehicles is:

$$\hat{MI} = 0.96X_1 + 1.28X_2 + 3.90X_3 - 3.97$$

Substituting the factor numbers from the revised formula for X_1 , X_2 , and X_3 (see paragraph 4) gives

$$\hat{MI} = 0.96\left[\frac{(1) \times (2)}{(3) \times (4)} \times (7) \times (8)\right]$$
$$+ 1.28\left[(5) \times (7) \times (8)\right] + 3.90\left[(6) \times (7) \times (8)\right] - 3.97$$

The equation above can be simplified as follows:

$$\hat{MI} = \left(\left\{0.96\left[\frac{(1) \times (2)}{(3) \times (4)}\right] + 1.28 \times (5) + 3.90 \times (6)\right\} \times (7) \times (8)\right) - 3.97$$

<u>Reliability of formulas</u>

8. <u>Multiple correlation coefficient (R^2).</u> The multiple correlation coefficient $\left[1.00 - \frac{\Sigma(Y - \hat{Y})^2}{\Sigma(Y)^2 - \frac{\Sigma Y^2}{N}}\right]$ is a statistical measure of how several variables are associated with each other. This coefficient measures the success of estimating the dependent variable (MI) from the three independent variables (vehicle factors in combination). The R^2 obtained from the analysis of the original and revised formula factors was 0.94 and 0.99, respectively, which indicates that the correlation between predicted and experimental MI for both methods is highly significant (greater than the 1 percent level of significance). Predicted values of MI and VCI using the multiple linear regression equations for the original and revised formulas are included in tables B1 and B2, respectively. Plots of predicted MI versus experimental MI for the linear regression of the original

and revised formulas are presented in plates B1 and B2, and predicted VCI (predicted MI converted to VCI) versus experimental VCI for the two formulas are presented in plates B3 and B4, respectively. The solid line in plates B1-B4 represents perfect correlation ($R^2 = 1.00$) and the nearness of the plotted points to these lines indicates graphically how close the equations predict MI and VCI for each of the 20 vehicles.

9. Standard error of regression equation. Another measure of the accuracy of the formulas is obtained from the standard error of the regression equation $\sqrt{\frac{(Y - \hat{Y})^2}{N - 1}}$. The deviations were ± 22.5 and ± 8.7 MI units, respectively, for the original and revised formulas. The R^2 values of 0.94 and 0.99 and the standard deviations from regression of ± 22.5 and ± 8.7 MI units for the original and revised formula factors indicate that the predicted values of MI obtained from the regression equation will be accurate within the above-stated limits 94 and 99 times out of a 100, respectively, for the two regression equations. The standard error of regression is included in plates B1 and B2 as dashed lines to show graphically where the predicted MI for each of the 20 vehicles plots in relation to these limits.

10. Deviation from regression and percent error. Other measures of the accuracy of the formulas are the deviations from regression ($\hat{Y} - Y$ = unit error), the percent error $\left(\frac{\hat{Y} - Y}{Y} \times 100\right)$, and the mean absolute deviation for the 20 vehicles. Unit and percent error for the linear regression equations for the original and revised factors for the 20 vehicles are included in tables B1 and B2. It should be noted that the algebraic deviations from regression will sum to zero; however, because of rounding to the nearest whole number for MI and VCI, the algebraic deviations shown in tables B1 and B2 do not sum to zero. The algebraic sign is included only to indicate if the equations are predicting high or low.

Comparison of Results of Predicting Vehicle Cone Index by the Four Formulas

11. Comparison of results of predicting VCI by the four mobility index formulas (original, regression of the original, revised, and regression of the revised) are made in the tabulation following this paragraph. The accuracy of each formula is indicated by the deviation of predicted from experimental VCI for the 20 vehicles previously discussed. The deviations are shown in the following tabulation as unit error and percent error:

No. of Tables with Detailed Results	Type Formula	Vehicle Cone Index: Unit Error, Absolute Average	Unit Error, Range	Percent Error, Absolute Average	Percent Error, Range
4	Original	19.0	1-132	26.4	2.0-130.0
B1	Original (regression)	9.1	0-34	18.7	0-91.9
4	Revised	3.6	0-9	6.1	0-14.5
B2	Revised (regression)	3.2	0-7	6.1	0-20.0

12. From the tabulation above, it can be seen that the original (regression) formula greatly improved the accuracy of predicting VCI over the original formula (unit error reduced from 19.0 to 9.1). The revised formula further improved VCI prediction accuracy over the original (regression) (9.1 to 3.6). The revised (regression) formula improved VCI prediction accuracy only slightly over the revised formula (3.6 to 3.2). The VCI's computed with the revised formula, generally, are lower than VCI's computed with the original formula for vehicles through the 5-ton rated pay-load range. For vehicles of 8- and 16-ton ranges, the revised formula VCI's are considerably higher than the original formula VCI's (see table A3, Appendix A). This is as desired since the original formula estimated VCI's too high for the lighter vehicles and estimated VCI's too low for vehicles in the heavy pay-load range (see table 4, main text).

Table B1

Data Pertinent to the Multiple Linear Regression Analysis of the Original Mobility Index Formula Factors

Vehicle		Original Formula Factors								Regression Variables												
No.	Nomenclature	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	X_1	X_2	X_3	Experimental MI, Y	Predicted MI, $\hat{Y}$	Experimental VCI	Predicted VCI	Unit Error MI	Unit Error VCI	Percent Error MI	Percent Error VCI	Vehicle No.
1	LeTourneau electric digger, model L-28	18.4	1.10	0.41	1.00	21.2	1.3	1.00	1.00	39.44	22.72	0.78	352	342	185	180	-10	-5	2.8	2.7	1
2	LeTourneau log stacker, model F	15.8	1.10	0.41	1.00	18.3	2.0	1.00	1.00	35.28	20.98	1.20	275	250	150	139	-25	-11	9.1	7.3	2
3	6-ton cargo truck, 6x6	20.7	1.00	0.18	1.00	5.8	1.3	1.00	1.05	84.57	13.65	0.82	110	128	75	83	+18	+8	16.4	10.7	3
4	2-1/2-ton cargo truck, 6x6	14.4	1.00	0.13	1.00	2.7	1.4	1.00	1.05	78.99	11.70	0.94	99	60	70	52	-39	-18	39.4	25.7	4
5	4-ton cargo truck, 6x6	14.9	1.00	0.18	1.00	4.3	1.5	1.00	1.05	63.78	12.65	0.94	88	75	65	59	-13	-6	14.8	9.2	5
6	5-ton XM520 GOER, 4x4, 15.00-34 tires	13.1	1.00	0.19	1.00	6.7	2.2	1.05	1.00	53.98	14.22	1.39	83	65	63	55	-18	-8	21.7	12.7	6
7	16-ton XM438E2 GOER, 4x4, without chains	13.0	1.10	0.37	1.00	9.6	3.0	1.00	1.05	34.35	16.05	1.89	81	49	62	47	-32	-15	39.5	24.2	7
8	16-ton XM438E2 GOER, 4x4, with chains	13.0	1.10	0.37	1.05	9.6	3.0	1.00	1.05	33.10	16.05	1.89	76	48	60	47	-28	-13	36.8	21.7	8
9	Tournadozer tractor, 4x4	14.9	1.00	0.26	1.00	7.8	1.4	1.05	1.00	45.85	14.91	0.88	76	130	60	84	+54	+24	71.1	40.0	9
10	3/4-ton M37 truck, 4x4, loaded	12.9	0.90	0.11	1.00	1.9	1.1	1.00	1.05	74.97	11.20	0.69	73	70	58	57	-3	-1	4.1	1.7	10
11	5-ton XM520 GOER, 4x4, 18.00-26 tires	14.3	1.00	0.23	1.00	6.7	2.1	1.05	1.00	49.94	14.22	1.32	70	69	57	57	-1	0	1.4	0	11
12	2-ton Meili Flex-Trac, 4x4, with chains	11.4	0.90	0.13	1.05	2.3	1.1	1.00	1.05	59.14	11.45	0.69	59	67	52	56	+8	+4	13.6	7.7	12
13	Bucket loader, 4x4	10.3	0.90	0.18	1.00	3.4	1.5	1.00	1.00	40.90	12.04	0.90	54	49	50	47	-5	-3	9.3	6.0	13
14	3/4-ton M37 truck, 4x4, empty	10.2	0.90	0.11	1.00	1.5	1.1	1.00	1.05	61.62	10.94	0.69	54	55	50	50	+1	0	1.9	0	14
15	Willys station wagon, 4x4	8.7	0.90	0.09	1.00	0.9	0.8	1.00	1.05	66.31	10.57	0.50	54	68	50	56	+14	+6	25.9	12.0	15
16	1-1/2-ton power wagon (modified)	8.2	0.90	0.23	1.00	2.4	1.5	1.00	1.05	30.56	11.51	0.94	37	24	42	36	-13	-6	35.1	14.3	16
17	2-ton Meili Flex-Trac, 6x6, with chains	7.6	0.90	0.13	1.05	1.5	1.1	1.00	1.05	42.76	10.94	0.69	33	43	40	45	+10	+5	30.3	12.5	17
18	Gama goat, 6x6	4.7	0.90	0.16	1.00	0.9	1.5	1.00	1.05	27.36	10.57	0.94	26	0	37	3	-26	-34	100.0	91.9	18
19	1/4-ton M151 truck (modified)	3.1	0.90	0.25	1.00	0.9	1.2	1.00	1.05	16.95	10.57	0.76	7	10	23	26	+3	+3	42.9	13.0	19
20	1/2-ton M274 carrier	4.2	0.90	0.09	1.00	0.3	1.1	1.00	1.05	35.40	10.19	0.69	5	18	20	32	+13	+12	260.0	60.0	20
															Absolute average		16.7	9.1	38.8	18.7	

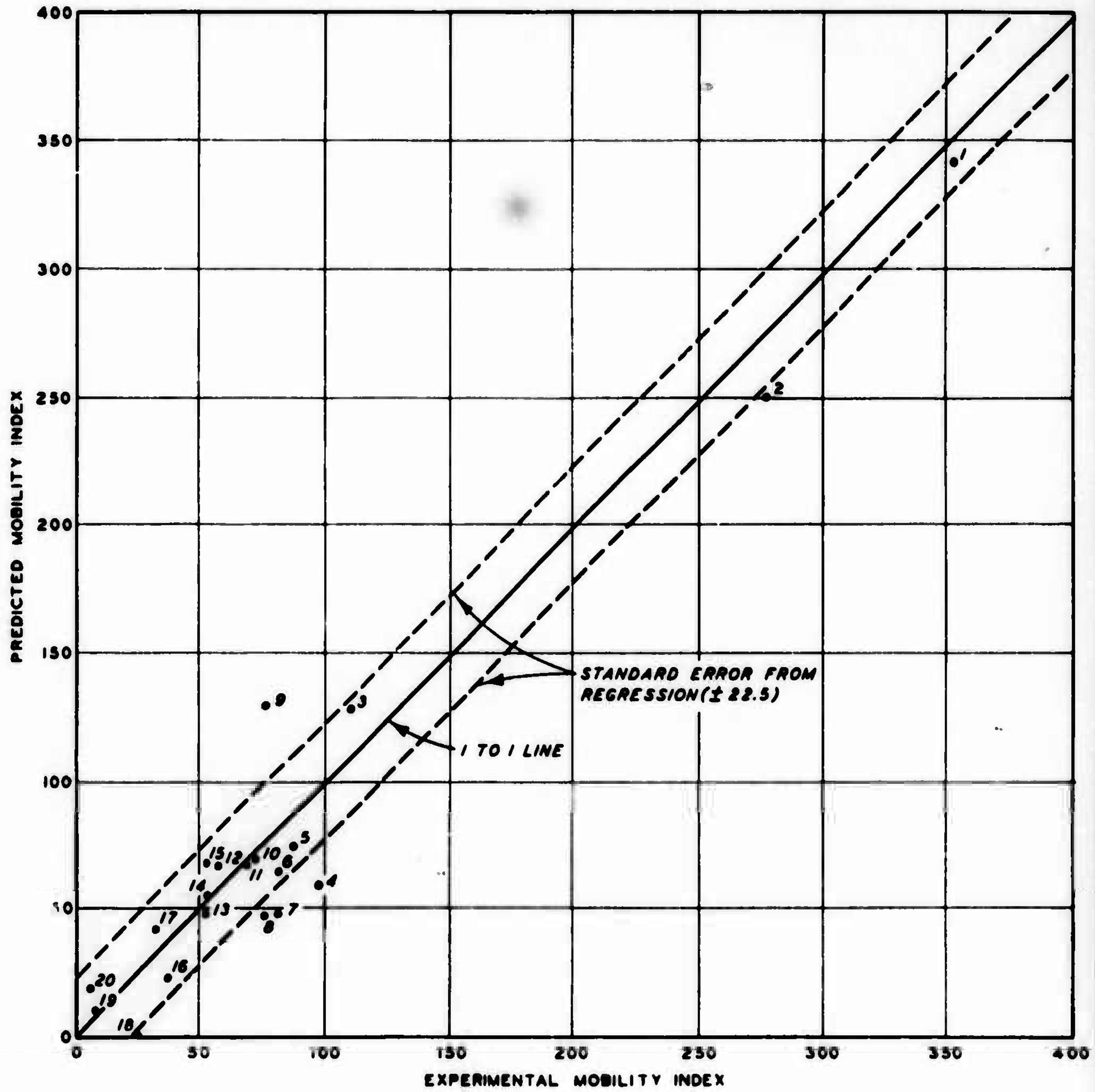
Note: Regression equation $\hat{Y} = 0.65X_1 + 26.34X_2 - 102.84X_3 - 201.80$. No algebraic average (see paragraph 10, Appendix B).

Table B2

Data Pertinent to the Multiple Linear Regress Analysis of the Revised Mobility Index Formula Factors

	Vehicle	Revised Formula Factors								Regression Variables							Unit Error		Percent Error		
No.	Nomenclature	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	X_1	X_2	X_3	Experimental MI, Y	Predicted MI, $\hat{Y}$	Experimental VCI	Predicted VCI	MI	VCI	MI	VCI	Vehicle No.
1	LeTourneau electric digger, model L-28	17.2	8.70	0.43	1.00	21.2	1.3	1.00	1.00	348.0	21.2	1.3	352	363	185	190	+11	+5	3.1	2.7	1
2	LeTourneau log stacker, model F	14.8	7.02	0.43	1.00	18.3	2.0	1.00	1.00	241.6	13.3	2.0	275	259	150	143	-16	-7	5.8	4.7	2
3	6-ton cargo truck, 6x6	17.3	1.43	0.24	1.00	5.8	1.3	1.00	1.05	103.1	6.1	1.4	110	108	75	74	-2	-1	1.8	1.3	3
4	2-1/2-ton cargo truck, 6x6	13.3	1.23	0.20	1.00	2.7	1.4	1.00	1.05	81.8	2.8	1.6	99	84	70	63	-15	-7	15.2	10.0	4
5	4-ton cargo truck, 6x6	12.4	1.33	0.24	1.00	4.2	1.5	1.00	1.05	68.7	4.4	1.6	88	74	65	59	-14	-6	15.9	9.2	5
6	5-ton XM520 GOER, 4x4, 15.00-34 tires	13.9	1.49	0.25	1.00	6.7	2.2	1.05	1.00	82.8	7.0	2.3	83	94	63	68	+11	+5	13.3	7.9	6
7	16-ton XM438E2 GOER, 4x4, without chains	8.8	2.30	0.40	1.00	9.6	3.0	1.00	1.05	53.1	10.1	3.2	81	72	62	58	-9	-4	11.1	6.5	7
8	16-ton XM438E2 GOER, 4x4, with chains	8.8	2.30	0.40	1.05	9.6	3.0	1.00	1.05	50.6	10.1	3.2	76	70	60	57	-6	-3	7.9	5.0	8
9	Tournadozer tractor, 4x4	11.1	1.81	0.31	1.00	7.8	1.4	1.05	1.00	64.8	8.2	1.5	76	75	60	59	-1	-1	1.3	1.7	9
10	3/4-ton M37 truck, 4x4, loaded	12.1	1.17	0.19	1.00	1.9	1.1	1.00	1.05	74.5	2.0	1.2	73	75	58	59	+2	+1	2.7	1.7	10
11	5-ton XM520 GOER, 4x4, 18.00-26 tires	12.0	1.49	0.28	1.00	6.7	2.1	1.05	1.00	63.9	7.0	2.2	70	75	57	59	+5	+2	7.1	3.5	11
12	2-ton Meili Flex-Trac, 4x4, with chains	11.4	1.20	0.20	1.05	2.3	1.1	1.00	1.05	65.1	2.4	1.2	59	66	52	55	+7	+3	11.9	5.8	12
13	Bucket loader, 4x4	9.5	1.28	0.24	1.00	3.4	1.5	1.00	1.00	50.7	3.4	1.6	54	55	50	50	+1	0	1.9	0.0	13
14	3/4-ton M37 truck, 4x4, empty	9.7	1.15	0.19	1.00	1.5	1.1	1.00	1.05	58.7	1.6	1.2	54	59	50	52	+5	+2	9.3	4.0	14
15	Willys station wagon, 4x4	9.0	1.01	0.17	1.00	0.9	0.8	1.00	1.05	53.5	0.9	0.8	54	52	50	49	-2	-1	3.7	2.0	15
16	1-1/2-ton power wagon (modified)	5.7	1.21	0.28	1.00	2.4	1.5	1.00	1.05	24.6	2.5	1.6	37	29	42	38	-8	-4	21.6	9.5	16
17	2-ton Meili Flex-Trac, 6x6, with chains	7.6	1.15	0.20	1.05	1.5	1.1	1.00	1.05	41.6	1.6	1.2	33	43	40	45	+10	+5	30.3	12.5	17
18	Gama goat, 6x6	4.2	1.04	0.22	1.00	0.9	1.5	1.00	1.05	19.9	0.9	1.6	26	22	37	35	+4	-2	15.4	5.4	18
19	1/4-ton M151 truck (modified)	2.4	0.95	0.30	1.00	0.9	0.2	1.00	1.05	7.6	0.9	1.3	7	9	23	25	+2	+2	28.6	8.7	19
20	1/2-ton M274 carrier	3.4	0.35	0.17	1.00	0.3	1.1	1.00	1.05	7.0	0.3	1.2	5	8	20	24	+3	+4	60.0	20.0	20
															Absolute average		6.7	3.2	13.4	6.1	

Note: Regression equation $\hat{Y} = 0.96X_1 + 1.28X_2 + 3.90X_3 - 3.97$. No algebraic average (see paragraph 10, Appendix B).



REGRESSION EQUATION

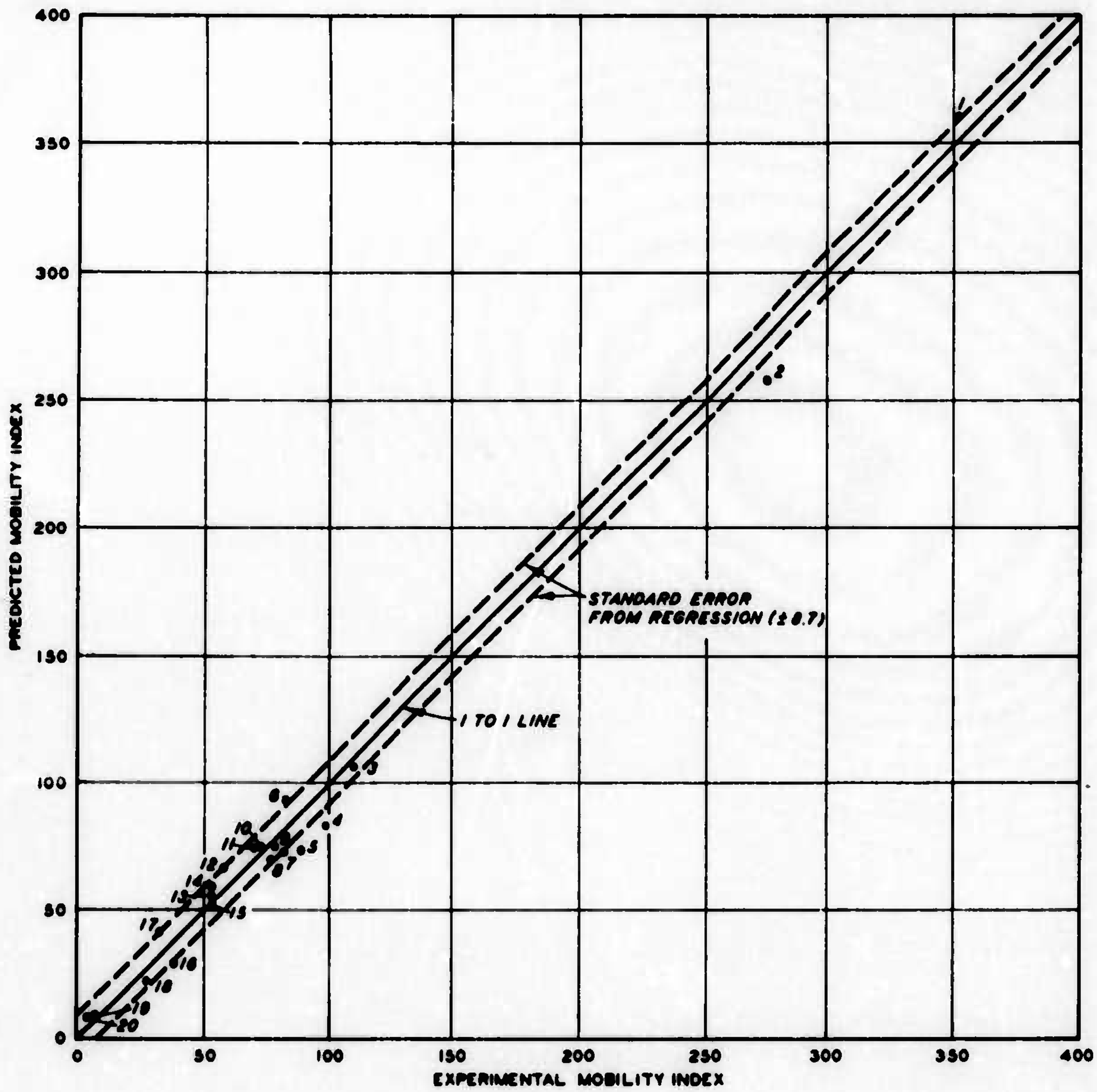
$$\widehat{MI} = 0.80 \times (7) \times (8) \left[0.65 \left(\frac{(1) \times (2)}{(3) \times (4)} \right) + 28.34 \times (5) - 102.84 \times (6) \right] + 68.10$$

NOTE: NUMBERS BY PLOTTED POINTS ARE VEHICLE NUMBERS FROM TABLE B1.
PREDICTED MOBILITY INDEX BY MULTIPLE LINEAR REGRESSION OF ORIGINAL FORMULA FACTORS.

PREDICTED VS EXPERIMENTAL MOBILITY INDEX

ORIGINAL FORMULA FACTORS

PLATE B1



REGRESSION EQUATION

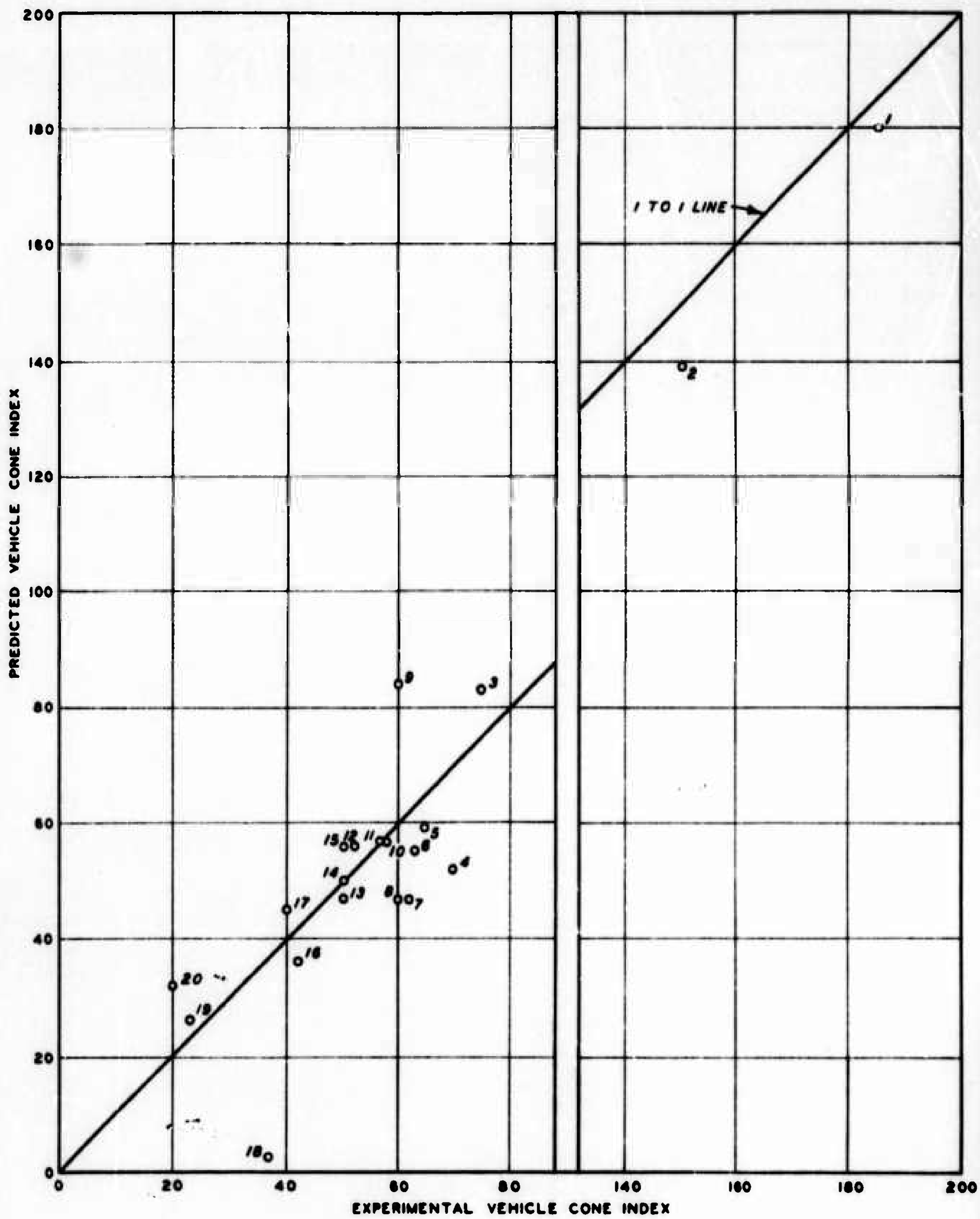
$$\left\{\left[0.96\left(\frac{(1)\times(2)}{(3)\times(4)}\right)+1.28\times(5)+3.80\times(6)\right]\times(7)\times(8)\right\}-3.87$$

NOTE: NUMBERS BY PLOTTED POINTS ARE VEHICLE NUMBERS FROM TABLE B2.
PREDICTED MOBILITY INDEX BY MULTIPLE LINEAR REGRESSION OF REVISED FORMULA FACTORS.

PREDICTED VS EXPERIMENTAL MOBILITY INDEX

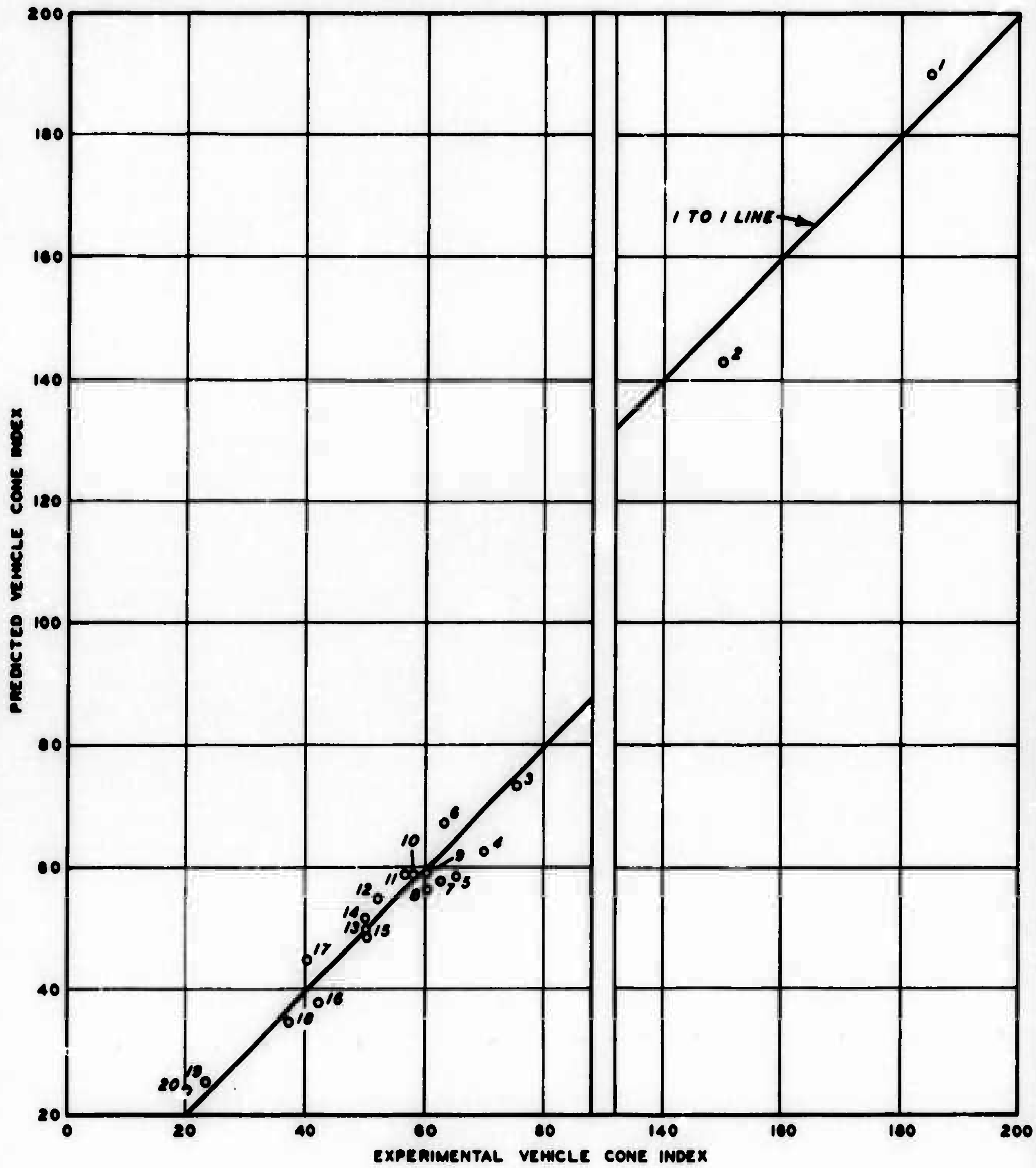
REVISED FORMULA FACTORS

PLATE B2



NOTE: NUMBERS BY PLOTTED POINTS ARE VEHICLE NUMBERS FROM TABLE B1.
PREDICTED VEHICLE CONE INDEX BY MULTIPLE LINEAR REGRESSION OF ORIGINAL FORMULA FACTORS.

PREDICTED VS EXPERIMENTAL VEHICLE CONE INDEX
ORIGINAL FORMULA FACTORS



NOTE: NUMBERS BY PLOTTED POINTS ARE VEHICLE NUMBERS FROM TABLE B2.
PREDICTED VEHICLE CONE INDEX BY MULTIPLE LINEAR REGRESSION OF REVISED FORMULA FACTORS.

PREDICTED VS EXPERIMENTAL VEHICLE CONE INDEX

REVISED FORMULA FACTORS

PLATE B4

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13. ABSTRACT

In 1955, formulas for computing mobility indexes (MI) and converting them to vehicle cone indexes (VCI), or minimum soil strength required for 50-pass go-no go, for current military wheeled and tracked vehicles were reported. Subsequent trafficability tests with vehicles having construction-equipment-type tires showed that the computed VCI did not agree closely with test results. To obtain data to determine whether the MI formula for self-propelled wheeled vehicles needed modification, field tests were run with small vehicles equipped with large, high-flotation tires, very large vehicles with very heavy wheel loads, and a few conventional vehicles. Main test purposes were to obtain data to determine experimentally 50-pass VCI for some untested vehicles and from these and other test results develop an MI formula for a wide range of vehicle weights and tire sizes. Although only 16 vehicles were tested, VCI's were determined for 20 vehicle "types." To determine if VCI prediction could be improved, a statistical analysis was made on both the original and revised MI formulas using a multiple linear regression technique. General conclusions are that considerable improvement can be made in the original formula merely by using the multiple regression equation; further improvements can be made by using the revised formula; use of the revised multiple regression formula provides only slight improvement over use of the revised formula. Thus, it is suggested that the revised formula be adopted. Appendix A gives the original and revised MI formulas and compares computed VCI's for some standard and experimental vehicles using the two formulas. Appendix B is a detailed analysis and evaluation of the original and revised MI formula factors by the multiple linear regression technique.

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